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A NEW EXPERIMENTAL METHOD FOR HADRON FIELD RESEARCH AND OPERATIVE DOSE CONTROL ON ACCELERATORS AND ACCELERATOR-BASED FACILITIES

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INTRODUCTION

A successful designing and application of high energy accelerators, colliders, physical setups and accelerator based facilities such as spallation neutron sources depend in large degree on a knowledge and account of radiation conditions connected with the characteristics of secondary hadron fields. The availability of the total information about hadron field characteristics at the research and development stage of accelerator and setup designing allows one to optimize shield and detector constructions and physical experiments to rise result reliability and to cut down expenses. The absence of simple experimental technique for an analysis of the spatial-energy distribution of hadrons with a hard energy spectrum leads only to a broad use of theoretical methods for the evaluation of dose, hadron fluence and the differential distributions of hadrons in the shield, experimental area and calorimeters. However, typical differences between the predictions of such well-known codes as FLUKA[1], CALOR (HETC)[2] et al. and between theoretical predictions and experimental results reach a factor of ~2-3. And the absence of reliable experimental data base for the intermediate and high energy region is a serious problem on the way to theoretical code development. So at present the role of experimental methods is very important both for hadron fluence measurements with low errors and for theoretical code testing.

Such advanced experimental technique of the spatial-energy mapping of hadron distribution for a fast analysis of radiation conditions and an operative dose control on accelerators and accelerator based facilities has been developed at the LHE/JINR by physicists from Dubna, Radium Institute in Saint Petersburg and Moscow Radiotechnical Institute of the Russian Academy of Sciences[3,4].

METHOD

The threshold fission detectors technique is one of the known experimental methods for neutron field research in the traditional energy region for neutron physics, $E < 10$ MeV. A standard set of detectors for neutron spectrometry consists of fission detectors with thin layers of ^{235}U (with cadmium and boron filters), ^{237}Np, ^{238}U and ^{232}Th. This method with the registration of fission fragments by solid state nuclear track detectors, SSNTD (6-μm polyethyleneterephtalate, PETP) was taken as the basis for the creation of a novel experimental method of fast analysis of hadron fields with a hard energy spectrum. The development of the method included four following steps:

1) automation of track counting in PETP;

2) designing of new detectors with high-energy thresholds;

3) a study of background and distorting effects and optimization of hadron detector construction;

4) testing method in the field of a spallation neutron source.

The collaborators of the Radium Institute (Saint Petersburg) have developed and made the first fully-automatic spark counter of tracks /5/. In this device all components (a high-voltage block, a scaler and so on) are integrated, and all operations of track counting for a single detector are performed automatically according to the program pre-set at the front panel. The instrument has the following operating characteristics: the counting time of tracks with one detector for a track density of ~ 1000 cm^{-2} does not exceed 3 min; the measured linear range of the traversing track density is 2000–4000 cm^{-2} (a fragment fluence of 4000–8000 cm^{-2}); the root mean-square deviation of the results in the above-mentioned range of the track density is $<$ 2%. The weight of the instrument is 3 kg; the dimensions are 250x230x120 mm; the power consumption is 15 W. Now a new automated spark counter connected with a computer is designed.

The hadron detector consists of the above-mentioned standard set of fission and new detectors: the fission detector with a thin ^{209}Bi layer (~ 90 MeV threshold) and the spallation detectors with thick layers of titanium, copper and cadmium (several hundred MeV threshold). The spallation detectors representing a new kind of threshold detectors have been studied at the Dubna synchrophasotron using a proton beam and a spallation neutron source /3,4/. The energy dependence of the efficiency of these spallation detectors is shown in fig. 1. Spallation fragments like fission fragments are registered by the SSNTDs (for PETP film the threshold value of nuclear fragment charge Z_{th} = 5). The efficiency of the full set of threshold detectors with the layers of ^{235}U, ^{237}Np, ^{238}U, ^{232}Th, ^{209}Bi, copper and cadmium is shown in fig. 2. The hadron detector construction is schematically shown in fig. 3.

In order to correct experimental data, the following distorting and background effects have been studied: 1) angular asymmetry of the fission and spallation fragments; 2) registration of the fragments from the backings ("backing effect"); 3) spallation of nuclei of a fissile layer and 4) own SSNTD counting.

The experimental technique includes the following stages of operations:

1) irradiation of the detectors in the investigated hadron field;

2) etching of SSNTDs (60 min. at a temperature of 60±0.1 °C in a KOH solution with a density of 1.252 g/cm² at 20 °C);

3) track counting with an automated spark counter;

4) data correction;

5) reconstruction of the hadron fluence spatial-energy distribution by the iteration procedure realized in the computer code RESTOR /3/.

Prior information about the relation of the yields of different hadrons and the spectrum shape as input data for the iteration code can be taken from the pre-

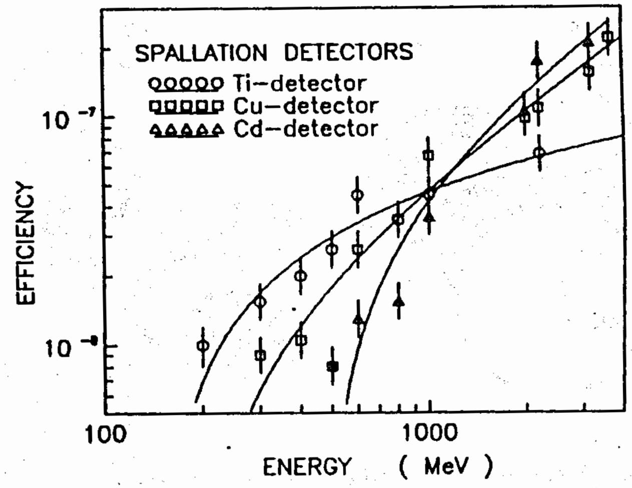

Fig. 1. Efficiency of spallation detectors with thick layers of titanium, copper and cadmium.

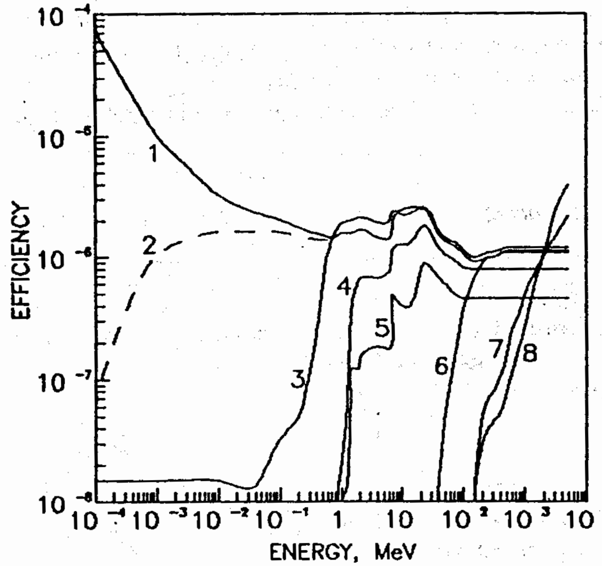

Fig. 2. Efficiency of the full set of threshold detectors (hadron-detector) consisting of 1 mg/cm² fissile layers of ^{235}U(1), ^{235}U with 2 g/cm² boron filter (2), ^{237}Np (3), ^{238}U (4), ^{232}Th (5), ^{209}Bi (6) and thick layers of copper (7) and cadmium (8). The values of curves (6-8) were increased by a factor of 10.

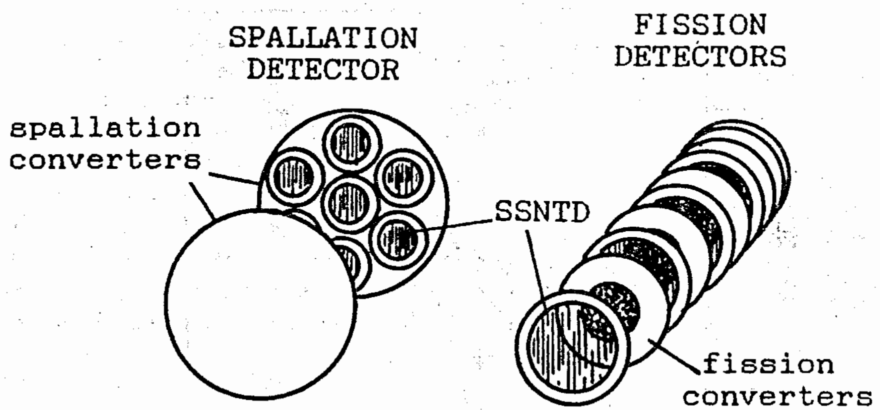

Fig. 3. Schematic drawing of the hadron detector construction.

dictions of experiments and calculations. The investigations of our and other authors with thick targets bombarded by relativistic protons and heavy ions have shown that targets with a thickness above ~ 100 g/cm^2 are an intense source of neutrons and their yield is larger than that of charged particles by an order for hadron energies above 20 MeV or by two orders for all energies. However, if even this information is absent, the errors will be smaller than 25%.

The main characteristics of the described experimental method are given in the table.

Table. Characteristics of the threshold detectors method

Overlapped energy region	thermal – several GeV
Typical number of hadron detectors in one experiment	tens – hundreds
SSNTD (PETP) characteristics	
Sensitivity to particles:	
3 MeV neutrons	$<10^{-12}$
14 MeV neutrons	$<10^{-11}$
5.47 MeV α-particles (2π-geometry)	$<5\cdot10^{-11}$
fission fragments (2π-geometry)	0.515
Effective nuclear charge threshold	5
Detector characteristics	
Maximum value of efficiency	
1 mg/cm^2 fission detector	$\sim3\cdot10^{-6}$
spallation detector	$\sim4\cdot10^{-7}$

Dimension	
one threshold detector	ϕ 19x0.3 mm
hadron detector	ϕ 20x3 mm
Detector processing	
Counting time for one SSNTD	3 min
Total time of data processing for 100 hadron detectors (~ 600 threshold detectors):	
using one automated counter	30 days
using five automated counters	7 days
Optimum statistics	2000–4000 cm^{-2}
Typical total methodical error of hadron fluence:	
low-energy region	6–10%
high-energy region	15–25%
Possibility of reprocessing of SSNTD	yes
Time of information storage in SSNTD	years

TESTING OF METHOD

For testing the threshold detectors technique in the hadron field with a hard spectrum, we have performed a series of experiments with a spallation neutron source based on the Dubna synchrophasotron using thick lead ϕ20x20 cm and ϕ20x60 cm targets. A three-component analytic representation of the neutron energy spectrum [6] was used as a zero-approximation of the spectrum shape. Realistic

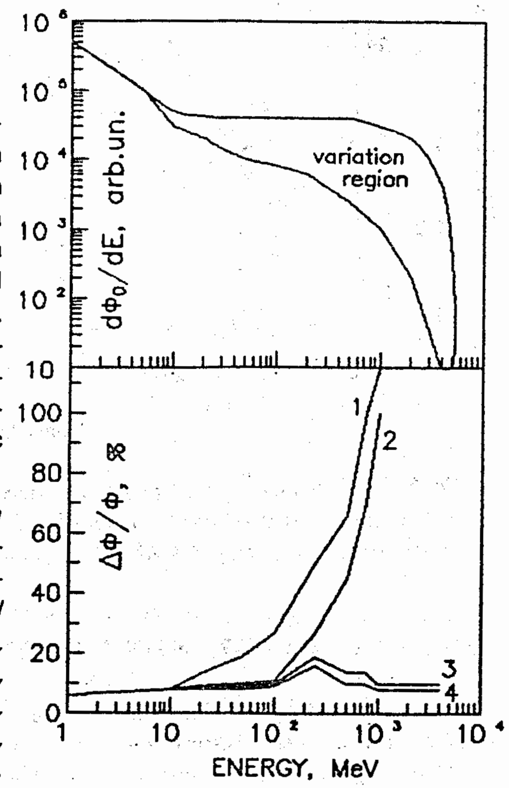

Fig.4. Range of neutron spectrum shape variation (A) and respective relative uncertainty of fast neutron fluence for different sets of threshold detectors (B): 1 – ^{237}Np, ^{238}U, ^{232}Th; 2 – ^{237}Np, ^{238}U, ^{232}Th, ^{209}Bi; 3 – ^{237}Np, ^{238}U, ^{232}Th, ^{209}Bi, cadmium; 4 – ^{237}Np, ^{238}U, ^{232}Th, ^{209}Bi, copper, cadmium.

variation of representation parameters gives a very large discrepancy between relative high-energy neutron fluence uncertainty values for some different threshold detectors sets as shown in fig.4. The addition of high-energy threshold detectors to the detector set leads to a strong decrease of this uncertainty.

A good agreement between the time of flight and threshold detectors technique results for the lead target ϕ20x20 cm bombarded by 2.55 GeV protons is shown in fig. 5. The TOF proton spectrum is also shown in fig. 5.

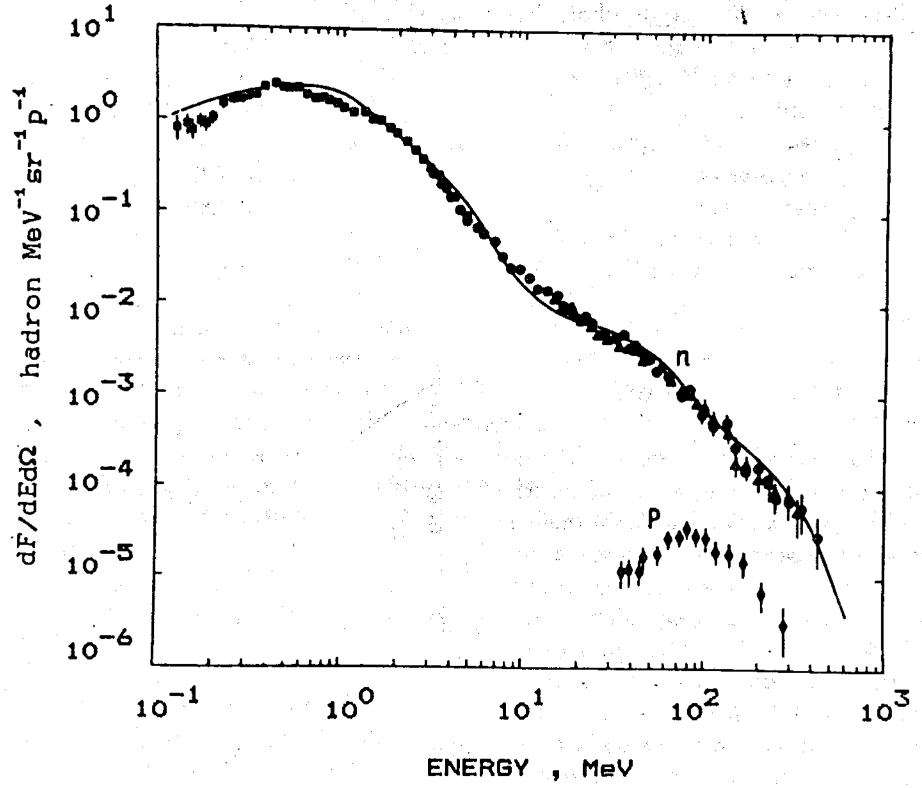

Fig.5. TOF spectra of neutrons and protons (points) and the energy spectrum of neutrons measured with threshold detectors technique (curve) at an angle of 90° for the lead target ϕ 20x20 cm bombarded by 2.55 GeV protons.

POSSIBLE APPLICATIONS OF THE METHOD

Taking into account simplicity of the described method and the possibility of a fast and accurate hadron field analysis with a few hundred detectors, we suppose that in future this technique can find broad application in different branches

of science and technology where proton and heavy-ion intense accelerators are used.

Recently the threshold detectors technique has been used to investigate the neutron field of the extended lead target ϕ20x60 cm (spallation neutron source) irradiated by protons and deuterons with an energy of 1–4 GeV [7]. The experimental results of neutron angular distributions for 3.65-GeV protons bombarding the lead target ϕ20x60 cm are shown in fig.6.

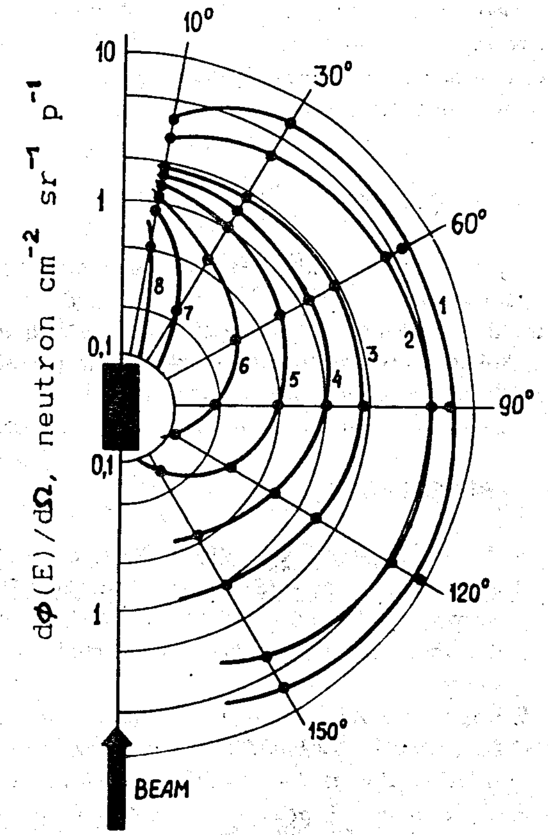

Fig.6. Angular neutron fluence distribution in different energy groups for the lead target ϕ20x20 cm bombarded by 3.65-GeV protons: 1 – all neutrons, 2–8 – neutrons with energy above 1, 6, 20, 50, 100, 250 and 500 MeV, respectively.

The calculation predictions show that neutrons make a main contribution to the radiation damage and dose and determine the time of proper operation of experimental setups on the colliders [8]. Background hadron radiation in the experimental area at a luminosity of 10^{33} $cm^{-2}s^{-1}$ gives a fluence of $F \sim 10^{11} \div 10^{15}$ cm^{-2} per year or $\sim 10^{7} \div 10^{11}$ cm^{-2} per hour. The fluence $F \sim 10^{9} \div 10^{10}$ cm^{-2} corresponds to optimum statistics for the threshold detector efficiency $\epsilon \sim 10^{-6} \div 10^{-7}$. The time of threshold detector irradiation in this hadron field is $\sim 10^{-1} \div 10^{2}$ hours. This time can be corrected using detectors with another value of efficiency.

Another application of the method is to study the hadron distribution in experimental setups and calorimeters and to measure the hadron leakage. The required hadron fluence is $\sim 10^{10} \div 10^{12}$ cm^{-2} what is approximately by 3–4 orders smaller than in the measurement with activation detectors. So, the method does not practically give the radiation damage and activation of setups and calorimeters.

The method of operative constant dose control is based on the application of thin-film breakdown counters of fragments, TFBC, [9] instead of SSNTD in hadron detectors. A few tens of such detectors placed in the experimental area will give dose/fluence information at any instant of time during an experiment. The typical dimension of a detector is about 2–4 cm, and on-line data processing by CAMAC electronics connected with a computer is used. If necessary, the accumulated data can be taken for a normalization of spatial-energy distribution obtained with a large number of detectors provided with the SSNTD.

CONCLUSION

In future we plan to develop the descirbed experimental method in two ways: 1) computer automation of track counting and 2) design of new high-energy threshold detectors and a more accurate study of detector's efficiency. Our plans on the use of this technique in neutron research at the JINR have been recently described in ref. [10].

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Новый экспериментальный метод исследования адронных полей и оперативного дозового контроля на ускорителях и установках на базе ускорителей

Описывается новый метод анализа пространственно-энергетического распределения адронов. Для детектирования адронов используется метод пороговых детекторов на основе реакций деления и расщепления ядер. Осколки деления и ядра-фрагменты регистрируются твердотельными трековыми детекторами на основе лавсана с off-line автоматическим подсчетом треков в детекторах. В качестве регистратора осколков деления используются также тонкопленочные пробойные счетчики с on-line обработкой информации. Приводятся характеристики метода и возможные наиболее перспективные его приложения в научных и прикладных исследованиях на ускорителях.

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A New Experimental Method for Hadron Field Research and Operative Dose Control on Accelerators and Accelerator-Based Facilities

A new method of hadron spatial-energy distribution analysis is described. The threshold detectors technique based on fission and spallation reactions is used for hadron detection. Fission and spallation fragments are registered with PETP film SSNTDs with off-line automated track counting. Fission fragments are also detected with TFBCs with on-line data processing. Method characteristics and different possible applications in fundamental and applied scientific research on accelerators are discussed.

The investigation has been performed at the Laboratory of High Energies, JINR.

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