УДК 539.1.03+539.1.043+539.125.52

SPALLATION NEUTRON SOURCE WITH HARD ENERGY SPECTRUM FOR DETECTOR COMPONENT TESTING AT THE DUBNA SYNCHROPHASOTRON

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A white neutron source has been recently constructed on the basis of the Dubna Synchrophasotron. A flux of neutrons with energies over the range up to several GeV is produced by spallation reactions using a pulsed proton/deuteron beam from the Synchrophasotron. The spallation neutron source on a Pb (W and ^{238}U in future) thick target has been intended for radiation damage studies of detector components of experimental setups at colliders.

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

Источник нейтронов с жестким энергетическим спектром для испытания компонент детекторов на дубненском синхрофазотроне

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Источник нейтронов с белым спектром был недавно разработан на базе дубненского синхрофазотрона. Поток нейтронов с энергиями до неск. ГэВ образуется за счет реакций расщепления ядер с использованием импульсного пучка протонов или дейтронов синхрофазотрона. Источник нейтронов расщепления на основе Pb (W и ^{238}U в будущем) толстой мишени предназначен для изучения радиационных повреждений компонент детекторов экспериментальных установок на коллайдерах.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

1. Introduction

Modern high luminosity colliders produce a high intensity field of secondary neutrons, charged hadrons and gamma-rays around an interaction point and at a large pseudorapidity region in experimental setups. The estimations show that the neutron fluence is up to $10^{13}-10^{15}$ n/cm^2 per year and determines the time of setup operation [1,2]. So, radiation damage studies are one of the main goals of the *R & D* stage of experimental setup design at colliders. The secondary neutrons have a hard energy spectrum overlapping a wide energy region up to several GeV. A neutron field with the same energy spectrum for detector component testing can be produced by the Spallation Neutron Source (SNS) based on an accelerator, where a proton/deuteron intermediate energy beam bombards a thick heavy metal target.

Some years ago the activity was begun on the creation of the radiation hardness test facility using several-GeV proton/deuteron beam of the Dubna Synchrophasotron [3—5]. First studies were carried out with various lead targets. The next step of source development is to reconstruct the SNS area around the Target-2 station and to use more compact targets from high density materials, W and ^{238}U.

2. Facility

A schematic plan view of the beam line with the experimental areas is shown in Fig.1. The proton/deuteron beam from the Synchrophasotron passes through a magnet system and then focuses at point F3 at Experimental Area 1 (EA1) where the Target-1 station is located with a neutron/charged hadron TOF spectrometer based on the detectors with plastic, stylben and NaJ(T1) scintillators. This spectrometer is used to obtain the energy spectra and yields of neutrons and charged hadrons emitted from various targets investigated and also to get the characteristics of neutron field of thick target as a prototype of the SNS located at the Target-2 station at the Experimental Area 2 (EA2) [6]. The beam comes to Experimental Area 2 (EA2) passing through next magnet system placed downstream Target-1. The beam hits neutron production Target-2 located at focus point F4 of the beam line where the experimental area is surrounded by a 3-m concrete shielding. There are two rotating arms with targets there, and one of them can be located at the beam line. After irradiation, the neutron production target can be turned away from the tested samples. A system of MWPCs and ionization chambers located upstream and downstream Target-1 and Target-2 measures the profile and intensity of the beam. The dimension of the beam spot on the front of the target in the vertical and horizontal directions is approximately 10 mm (FWHM). The beam has a time structure consisting of macropulses which can be of a various duration up to 400 ms in a different mode of beam burst. We expect to operate with approximately 8 macropulses/min with a beam intensity of up to $5 \cdot 10^{11}$ particles/macropulse. A new experimental method for neutron/hadron field mapping at accelerator-based facilities has been developed recently [7,8]. We are going to use this method for neutron field studies and an operative neutron flux control around Target-2 of the SNS. Brief information about experimental details of this technique is given in Appendix.

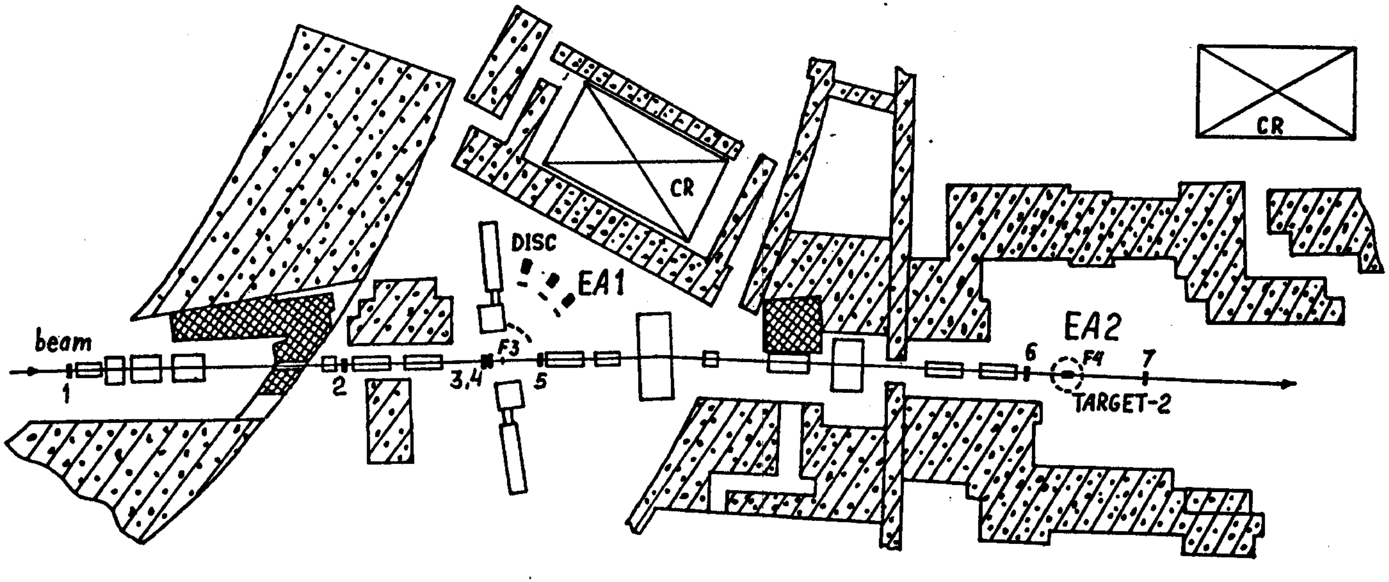


Fig. 1. A Schematic plan view of the Synchrophasotron beam line around the focus F3, F4: EA1, EA2 — Experimental Areas 1 and 2; CR — counting room; DISC — hadron spectrometer; 1,4—7 — MWPC; 2,3 — ionization chamber

3. Neutron Field of SNS Based on Lead Targets

In the last few years a lot of measurements with various thick lead targets irradiated by several-GeV protons/deuterons have been performed at the Dubna Synchrophasotron [3—5]. The energy spectra of neutrons for two lead targets 8 × 8 × 8 cm and ϕ20 × 20 cm measured by the TOF spectrometer at angles of 30, 90 and 150 deg. with 2.0- and 2.55-GeV proton beams are presented in Fig.2 and Fig.3, respectively. The obtained average energies of emitted neutrons for these are given in Table 1. A comparison of the energy spectra of the high-energy component of neutrons and charged hadrons for these targets is shown in Fig.4. The yield of charged hadrons is one order less than that of high-energy neutrons (the ratio of the yields depends on the emission angle) and approximately two orders less than the total neutron yield. All energy spectrum of neutrons and the spectrum of

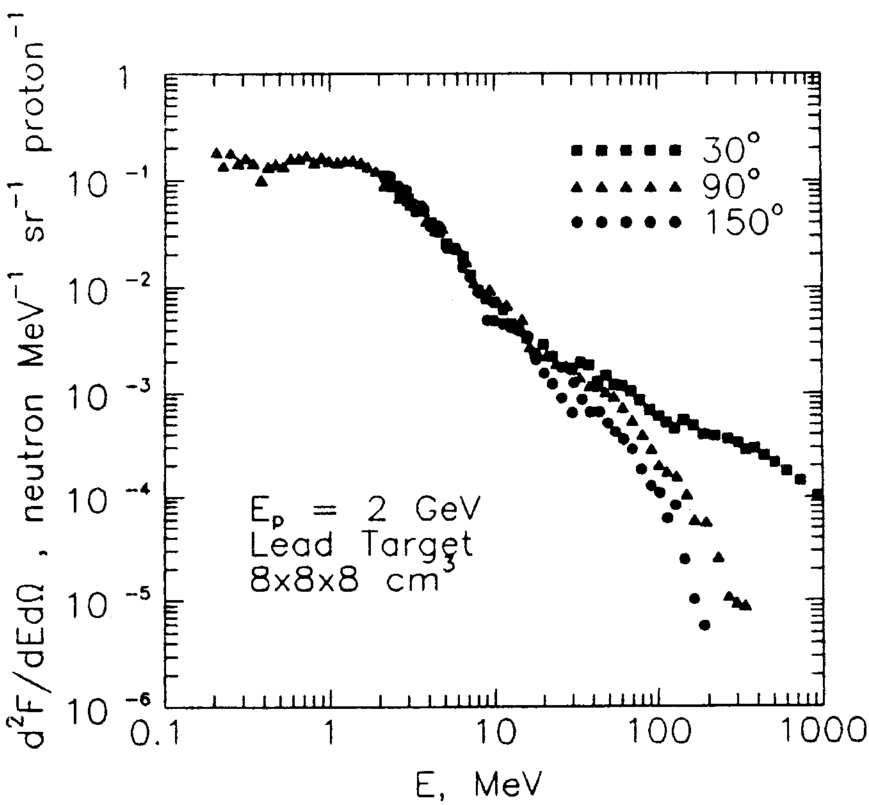


Fig.2. Energy spectra of neutrons for lead targer 8×8×8 cm bombarded by 2-GeV protons

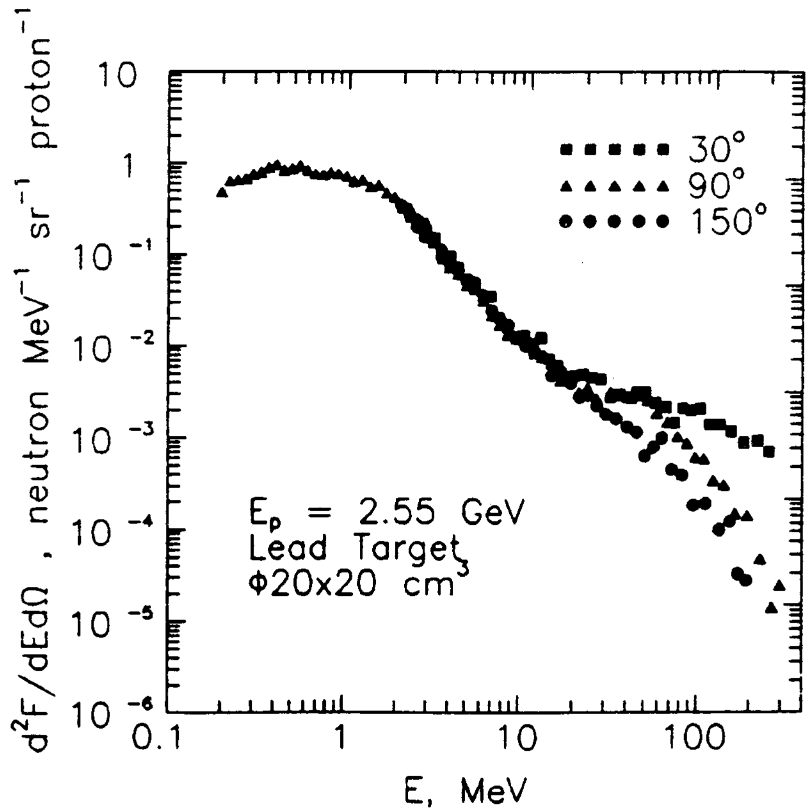


Fig.3. Energy spectra of neutrons for lead target ϕ20 × 20 cm bombarded by 2.55-GeV protons

protons emitted at an angle of 90 deg. from the lead target ϕ20 × 20 cm bombarded by 2.55-GeV protons is shown in Fig.5. A lot of measurements have been carried out with the threshold detector technique for an extended

Table 1. Average energy of neutrons (MeV)

Target (cm)	Beam	Energy (GeV)	Angle (deg.) 30	90	150
8×8×8	*p*	2.0	82.7	10.7	6.36
	d	2.0	29.5	8.12	4.53
ϕ20×20	*p*	2.55	21.6	7.31	4.38
	d	2.0	20.7	6.28	4.21

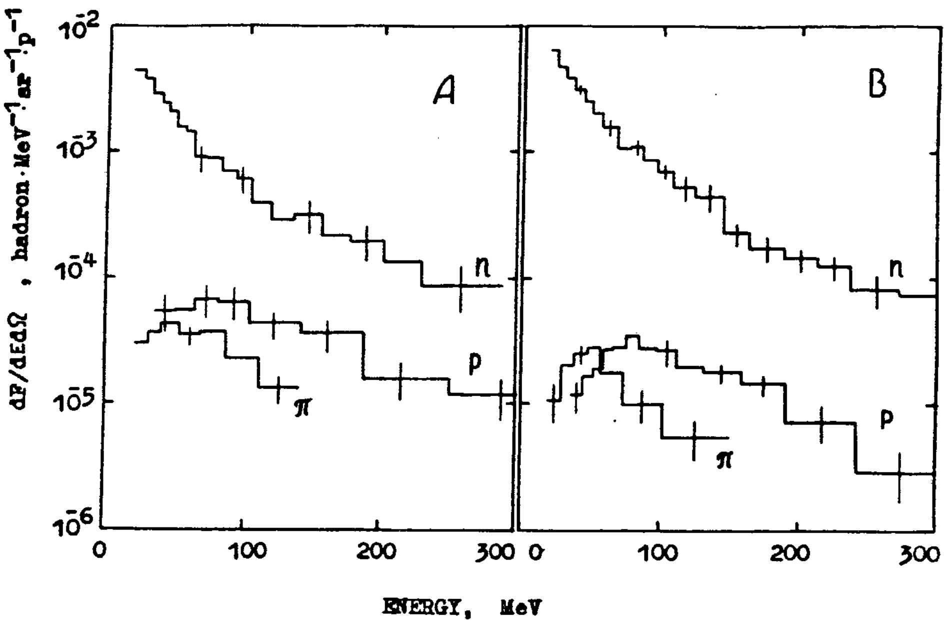


fig.4. Energy spectra of high-energy neutrons, protons and charged pions at angle of 90 deg. for two lead targets 8 × 8 × 8 cm (*A*) and ϕ20 × 20 cm (*B*) bombarded by 2.55-GeV protons

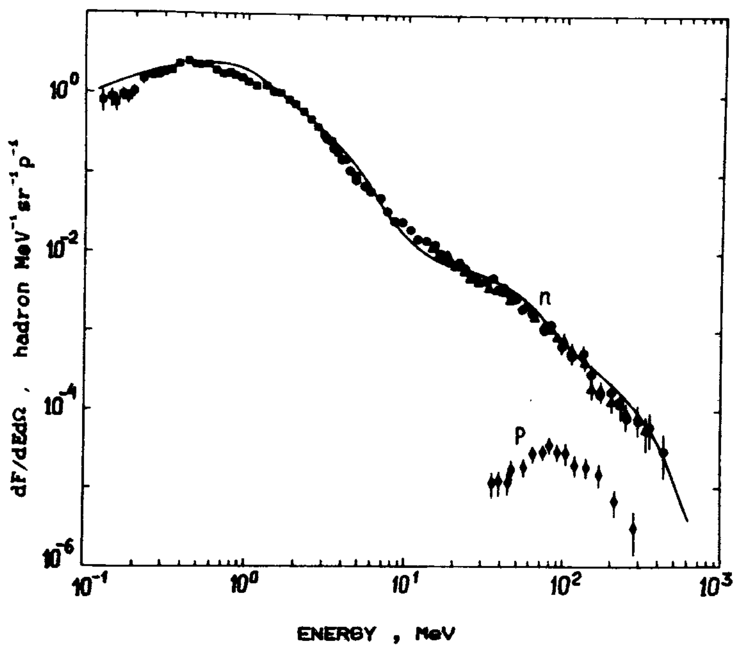


Fig.5. Energy spectra of neutrons and protons at angle of 90 deg. for lead target ϕ20×20 cm bombarded by 2.55-GeV protons

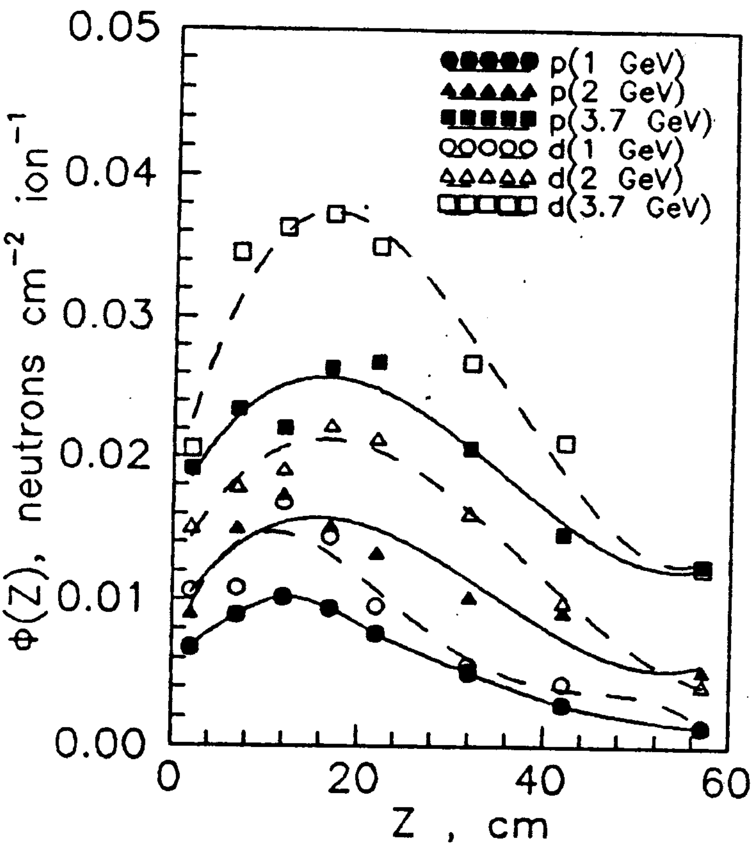


Fig.6. The distributions of neutrons along the side-surface of the lead target $\phi 20 \times 60$ cm bombarded by different energy protons and deuterons

Table 2. A dependence of the partial neutron yields for extended lead target $\phi 20 \times 60$ cm on an energy of proton/deuteron beam (n/p(d))

E_p (GeV)			E_d (GeV)		
1.0	2.0	3.65	1.0	2.0	3.76
All neutrons					
23.4 ± 3.0	44.2 ± 3.1	80.7 ± 6.9	26.2 ± 5.0	58.5 ± 8.2	98.9 ± 14.0
$E_n > 1$ MeV					
15.2 ± 2.1	27.5 ± 2.0	49.9 ± 4.5	14.6 ± 2.8	31.3 ± 4.7	56.6 ± 8.5
$E_n > 20$ MeV					
2.0 ± 0.3	4.7 ± 0.4	8.6 ± 1.0	1.8 ± 0.4	4.1 ± 0.7	8.2 ± 1.5

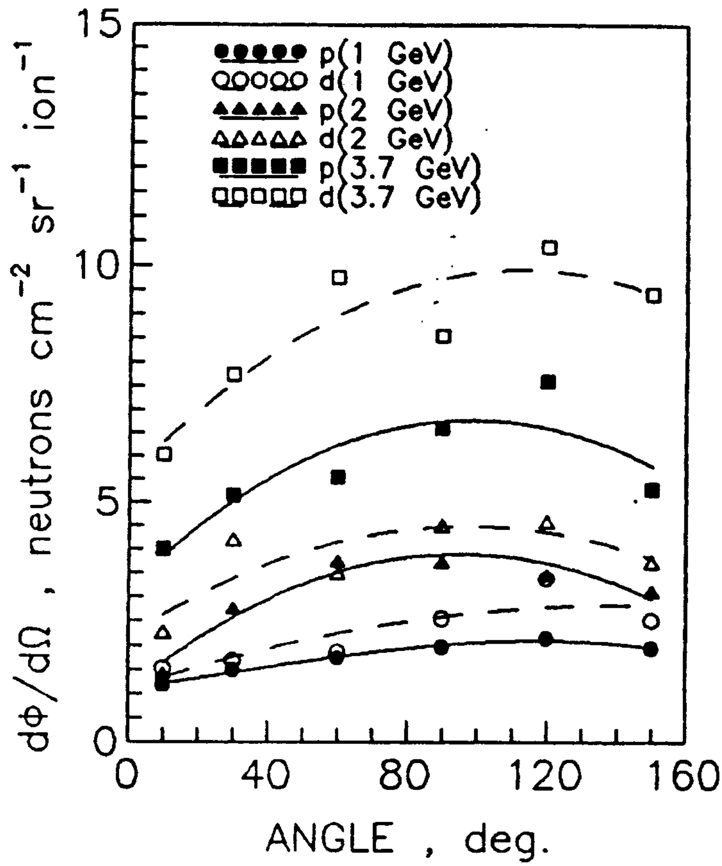


Fig.7. Angular distributions of neutrons for the lead target $\phi20 \times 60$ cm bombarded by different energy protons and deuterons

Table 3. Average energy of neutrons emitted from extended lead target $\phi20 \times 60$ cm

E_p (GeV)	$\langle E \rangle$ (MeV)	E_d (GeV)	$\langle E \rangle$ (MeV)
1.0	8.82	1.0	5.53
2.0	11.57	2.0	6.94
3.65	13.72	3.76	9.43

lead target $\phi20 \times 60$ cm [3,4]. The side-surface and angular distributions of neutrons for 1—3.7-GeV incident projectiles are shown in Fig.6 and Fig.7, respectively. The angular distribution for different energy groups of neutrons obtained for 3.65-GeV protons is presented in Fig.8. The partial

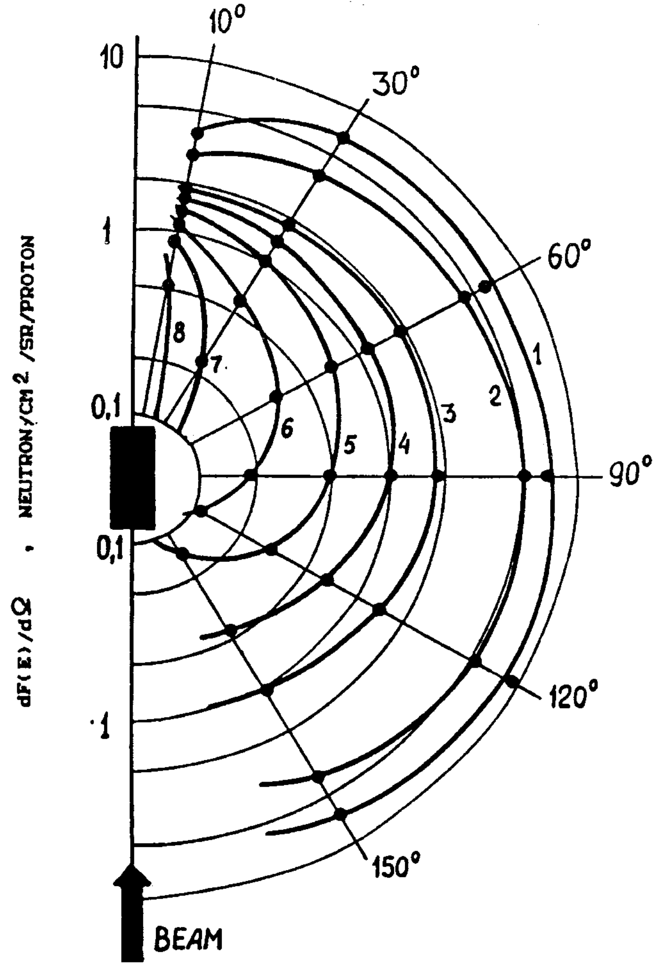


Fig.8. Angular distribution of neutrons in the different energy groups for the lead target $\phi 20 \times 60$ cm bombarded by 3.65-GeV protons. 1 — all neutrons; 2—8 — neutrons with the energy above 1, 6, 20, 50, 100, 250 and 500 MeV respectively

yields of neutrons for three energies of incident protons and deuterons and the average energies of neutrons emitted at the total solid angle are given in Table 2 and Table 3, respectively. The average energy rises with increasing the energy of beam particles and decreasing emission angle and target size. The total yield of neutrons per projectile approximately linearly depending on the kinetic energy of beam ions is ~ 145 n/p and ~ 180 n/d for 8-GeV projectiles, Fig.9.

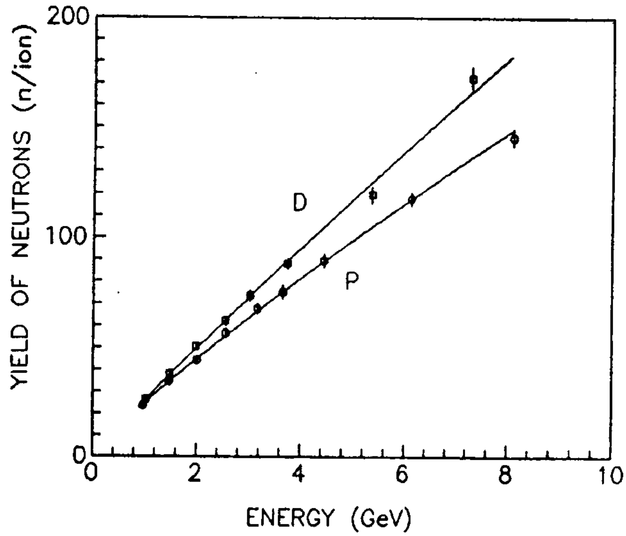


Fig.9. Energy dependence of the total neutron yield for lead target $\phi 20\times60$ cm bombarded by protons and deuterons

4. Neutron Flux Estimation

The estimation of the neutron flux for various neutron production targets has been carried out using the results of experimental studies and calculations for the 9-GeV/c proton beam with an intensity of $5\cdot10^{11}$ p/burst. Three types of targets (lead, tungsten or uranium-238 thick targets) for the reconstructed Target-2 station have been considered. These targets absorb about 80—90% of beam ions by inelastic interactions inside the target. The results of the estimation for different distances from the target are presented in Table 4.

Table 4. Neutron flux extimation for the neutron production targets

Distance from target	Target					
	Pb		W		^{238}U	
	$\frac{n}{cm^2\ burst}$	$\frac{n}{cm^2\ day}$	$\frac{n}{cm^2\ burst}$	$\frac{n}{cm^2\ day}$	$\frac{n}{cm^2\ burst}$	$\frac{n}{cm^2\ day}$
side-surface	$3\cdot10^{10}$	$3.4\cdot10^{14}$	$5\cdot10^{10}$	$5.6\cdot10^{14}$	$7.6\cdot10^{10}$	$8.6\cdot10^{14}$
20 cm	$1\cdot10^{10}$	$1\cdot10^{14}$	$1\cdot10^{10}$	$1\cdot10^{14}$	$1.7\cdot10^{10}$	$1.7\cdot10^{14}$
50 cm	$1.6\cdot10^{9}$	$1.6\cdot10^{13}$	$1.6\cdot10^{9}$	$1.6\cdot10^{13}$	$2.7\cdot10^{9}$	$2.7\cdot10^{13}$

The SNS based on the Dubna Synchrophasotron produce neutrons with a hard energy spectrum and a flux up to several 10^{14} $n \cdot cm^{-2}$ day^{-1}, and so one can see that this source represents a good facility for the radiation damage testing of detector components.

Appendix

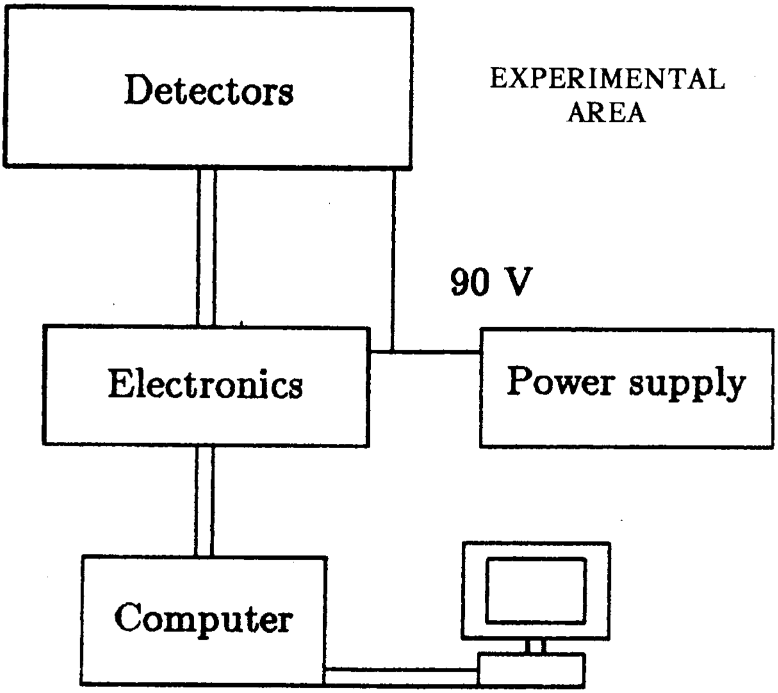
Advanced Technique for Neutron Field Research and Operative Dose Control

Method	threshold detectors technique [5]	
Detector	set of fissile and fragmenting layers connected with SSNTDs[1] or TFBCs[2]	
Efficiency	$\leq 10^{-5}$	
Number of detectors in a single experiment	for SSNTD technique — up to 1000 and more for TFBC technique — up to 100 and more	
On-line data accumulation	for SSNTD technique — NO for TFBC technique — YES	
Data processing	for SSNTD technique — off-line for TFBC technique — on/off-line	Iteration procedure
Properties of detector system	small dimensions and weight (portable) simple electronics	
Dimensions of detector	for SSNTD technique — $\phi 30 \times 10$ mm for TFBC technique — $30 \times 15 \times 10$ mm	

[1]solid state nuclear track detector (6 μm PETP)
[2]thin-film breakdown counter (Si)

TFBC TECHNIQUE

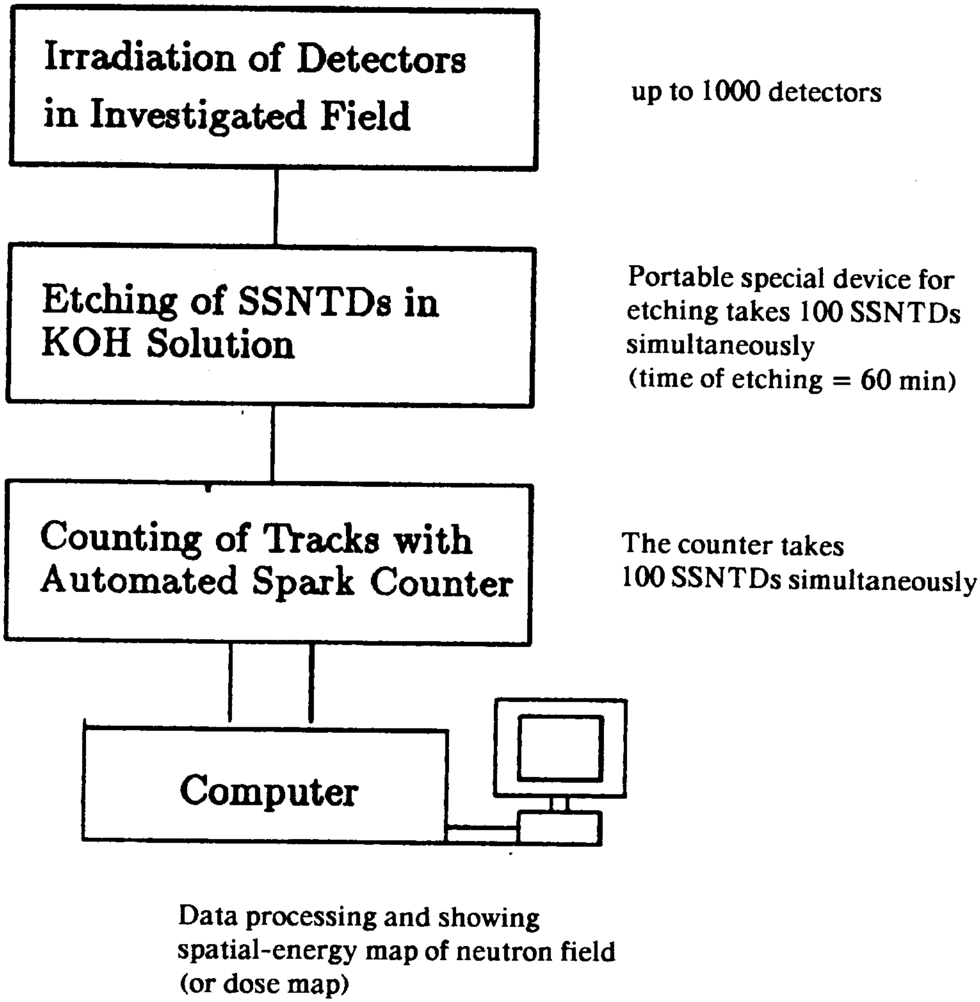
Automated method for operative neutron flux and dose control with on-line data accumulation and processing by computer



Data processing and showing spatial-energy map of neutron field (or dose map)

SSNTD TECHNIQUE

Semi-automated method for neutron field research



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Received on February 1, 1994.