OG.1.2.25

The INCA Project
II. Measurements of the neutron yield from a lead absorber for pion and proton projectiles

The INCA Collaboration

Abstract

As a part of the program of development of a new instrument called Ionization- Neutron Calorimeter (INCA) aimed at studying primary cosmic radiation, experimental data on average values and fluctuations of the neutron yield from a 60-cm-thick lead target are obtained. The target was exposed to pion and proton accelerator beams with energies of 4 and 70 GeV, respectively, and to an electron beam with an energy of 200 to 550 MeV. The experimental data obtained well agree with the results of a simulation by the SHIELD code used for development of INCA elements. It is shown that the same particle energy, the average neutron yield for electron projectiles is by the factor of approximately 50 lower than for hadrons.

1 Introduction

Characteristics of the ionization signal are well known. In the present study, the following basic properties of the INCA neutron signal are investigated: 1) The mean neutron yield as a function of the energy E0 of a primary hadron; 2) Neutron yield fluctuations for different E0; 3) Thermalization and diffusion times in the INCA layered structure; 4) Neutron signal distribution over the depth of the combined absorber composed of light and heavy substances.

2 Experimental prototype setup

We used an INCA with the absorber containing six lead layers each 10 cm thick and 20 cm × 20 cm in area interlayered by polyethylene plates 6 cm thick. SNM-18 ^{3}He proportional counters 30 cm long and 3 cm in diameter served as neutron detectors. Three counters were placed in holes drilled in polyethylene plate installed beyond every layer of the INCA absorber. The distances between centers of two adjacent counters of the same layer and between rows of counters in two neighboring layers were 6 and 15 cm, respectively. The total number of neutron counters in the INCA was 18.

To increase the detection efficiency for evaporated neutrons generated in the INCA, the lead absorber was completely screened by the polyethylene moderator and reflector 10 cm thick. The calibration measurements with Po−Be radioactive sources having activities of $2.25{\cdot}10^5$ and $2.25{\cdot}10^6$ s^{-1} were carried out to determine the detection efficiency for thermalized evaporated neutrons. The sources were placed in turn at different points of the INCA, and the total neutron counting rate in 18 INCA channels was determined. The average neutron detection efficiency obtained for 20 different positions of the sources within the INCA turned out to be $\langle\varepsilon\rangle = 7.4 \pm 0.4\%$.

The measurements of the neutron yield were performed in pion and proton beams with energies E_π= 4 GeV and E_p=70 GeV, respectively, at the IHEP U-70 accelerator (Ammosov V.V. et. al., 1998). The stretched beams were used in which the hadron flux within every burst was uniform during 2 s, and the total number of particles per beam burst did not exceed 10^4. Thus, the average time gap between hadrons incident onto the INCA was $\geq 200\mu$s.

Mean neutron yields $\langle n\rangle$ were also measured for electron energies of 0.2, 0.3, 0.4, 0.5 and 0.6 GeV at the LPI electron accelerator (Chubenko A.P. *et al.* 1998).

The INCA trigger provided (1) recording of the neutron signal induced by a single beam particle passing through the center of the INCA; (2) the absence of overlapping neutron signals induced by two or more primary hadrons; (3) suppression of signals caused by background particles.

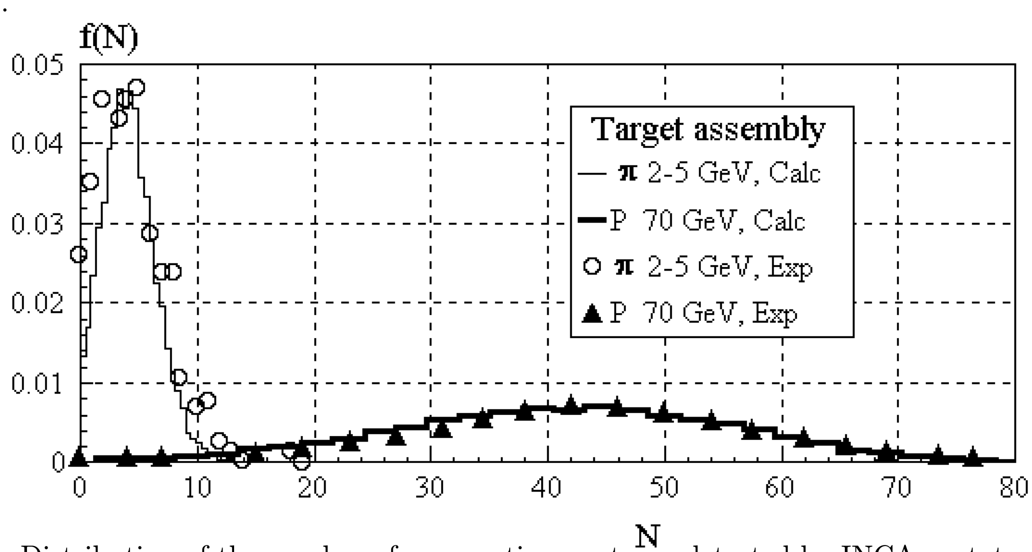

Figure 1: Distribution of the number of evaporation neutrons detected by INCA prototype.

Four scintillation counters S_1, S_2, S_3, and S_4 installed along the 20-m base were used to form the trigger. The counter S_1 was disposed immediately downstream of the beam collimator output, while the counter S_3 was installed directly in front of the INCA. The coincidences $S_1S_2S_3$ selected events corresponding to the incidence of beam particles onto the experimental setup. To reject background events and scattered beam particles, we used a large anticoincidence counter S_4 (30×30 cm^2) with a central hole 2 cm in diameter.

After the 10-μs delay, each trigger signal $S_1S_2S_3\bar{S}_4$ opened the time gate with a duration from 30 to 420 μs (depending on the measurement series). This is the time window that was used in the INCA for recording neutron signals.

3 Experimental results for hadrons and electrons at accelerator energies

Figure 1 demonstrates distributions $P(m)$ of a number m of neutrons detected by the INCA prototype in cascades that were initiated by protons ($E_p = 70$ GeV) and pions ($E_\pi = 4$ GeV). The distributions measured for protons are well approximated by a Gaussian, whereas those for pions are described by a superposition of two Poisson distributions. This fact is a consequence of the complicated nature of the process of nuclear disintegration in the INCA absorber under the action of beam particles.

The characteristic lifetime of neutrons in the INCA was determined using the dependence of the mean value $\langle m \rangle$ of recorded neutrons on the time-gate duration t. This lifetime turned out to be equal to $130 \pm 10\,\mu$s. All values of $\langle m \rangle$ given below correspond to $t = 330\,\mu$s, when the neutron collection efficiency attained, approximately, 95%.

For comparison, the calculated data for the mean number m of evaporated neutrons initiated by pions and protons with $E_0 = 4$ and 70 GeV, respectively, are also given in Figure 1. These data are obtained on the basis of the program package SHIELD (Dement'ev and Sobolevskii, 1993) based on the cascade-evaporation model of nuclear disintegration. The calculation was performed for real setup geometry with $\epsilon = 8\%$. There is a good agreement between calculation and experimental results.

In our experiment, we also have measured the distribution of a number of observed neutrons for the INCA with a combined absorber composed of light and heavy substances. To do this, in the INCA with the absorber made of complete polyethylene, we have replaced the polyethylene plate in

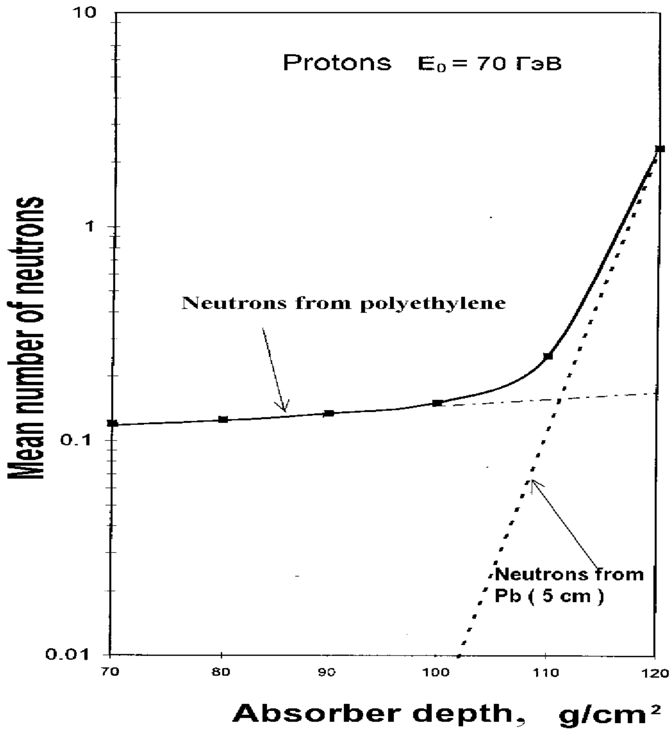

Figure 2: The mean number of neutrons recorded in the INCA vs. the polyethylene-absorber depth after introducing the lead plate 5 cm thick into the sixth row. The dashed line indicates the distribution of neutrons generated in lead, which was obtained by subtraction of the number of neutrons generated in polyethylene.

the sixth row by the lead plate 5 cm thick. The measurements were performed in the 70 GeV proton beam.

The experimental results are given in Fig. 2. As is seen, the replacement of polyethylene by lead led to a very sharp increase (by the factor of 20) a number of neutrons recorded in channels of the sixth row as compared to the first four rows. Such a polyethylene-lead transition effect is associated with the fact that the number of evaporated neutrons substantially depends on the mass number A of the absorber.

The presence of the transition effect for the neutron signals makes it reasonable to use INCA absorbers with a low mass number A (in the limiting case, $A = 1$) interlayered by thin plates of a heavy absorber ($A \approx 200$). Such a design of an INCA is important for experiments carried out on artificial satellites for which it is necessary to minimize the calorimeter weight under condition of preserving large geometry factor.

To compare values of the mean number $\langle \nu_n \rangle$ of generated neutrons for electromagnetic and nuclear cascades, the experimental data for electrons as well as for pions and protons, are presented in Fig. 3 together with the results of other experiments and calculated data (Gel'fand *et al.*, 1994) for a calorimeter with the lead absorber of both the infinitely large thickness and the finite thickness of 60 cm. The calculation was performed on the basis of the SHIELD and MC0 codes (Fedorova G.F. and Mukhamedshin R.A., 1994).

As follows from Fig. 3,

(a) the results of our measurements of the quantity $\langle \nu_n^h \rangle$ for pion and proton projectiles (black

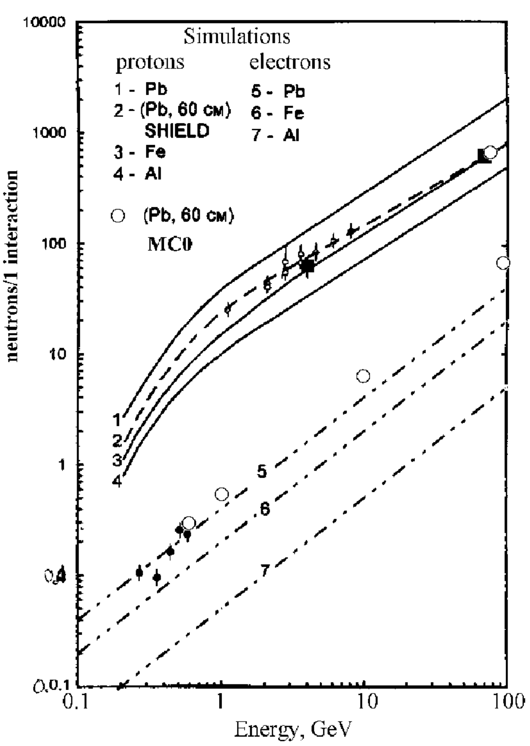

Figure 3: Energy dependence of the mean neutron yield for cascades initiated by electrons and hadrons in lead

squares) are in good agreement with data of other experiments (small cirles) and results of calculations based on the SHIELD and MC0 codes;

(b) the energy dependence of the mean neutron yield $\langle \nu_n(E) \rangle$ for nuclear cascades is proportional to $E^{0.8}$;

(c) the ratio of the mean neutron yields $\langle \nu_n^e \rangle$ and $\langle \nu_n^h \rangle$ for electromagnetic and nuclear cascades, respectively, at energies $0.6 - 1.0$ GeV is $\eta = \frac{\langle \nu_n^e \rangle}{\langle \nu_n^h \rangle} \sim 0.02$.

Using the value of η and distributions of the quantity ν_n^h in nuclear cascades initiated by protons and pions, we can estimate the probability ρ of erroneous identification of a proton-induced cascade as an electromagnetic one. For the INCA used by us (for which the neutron detection efficiency $\varepsilon = 7.4\%$), these estimates indicate that ρ decreases not only with the increasing the hadron energy but also with the increasing ε, so that ρ drops down to $\sim 10^{-3}$ as $\varepsilon \to 100\%$.

This work was supported in part by RFBR grant 98-02-17157.

References

Ammosov V.V., Chubenko A.P., Merzon G.I. *et al.* 1998, JTP Letters, **24**, no. 20 p. 35.

Chubenko A.P. *et al.* 1998, JTP Letters, **24**, no. 18 p. 67.

Dement'ev A.V. and Sobolevskii N.M. 1993, Proc. Special. Meeting Intermed. Energy Nucl. Data: Models and Codes, Paris, NEA OECD, 237.

Fedorova G.F. and Mukhamedshin R.A. 1994, Bull. Soc. Sci. Lettr. Lodz, Ser. Rech. Def., V. XVI, P. 137.

Gel'fand E.K., Man'ko B.V., and Sychev B.S. 1994, Izv. Akad. Nauk, Ser. Fiz. (Reports of Russian Ac. Sci., Phys. Ser.), vol. 58, no. 12, p. 41.