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HIGH ENERGY NEUTRON AND GAMMA-RADIATION GENERATED DURING THE SOLAR FLARES

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Problem of high energy neutrons and gamma rays
generation in the solar conditions is considered.
It is shown that due to a peculiarity of genera-
tion and propagation of neutrons corresponding
solar flares should be localized at high helio-
longitudes.

Solar neutrons have been detected only for two flares:
for June 21 1980 on board of the SMM satellite by Chupp et
al.[1] and for June 3 1982 simultaneously in several experi-
ments by SMM[1,2], neutron monitors[3,4,5] and registration
of protons of solar neutron decay origin [6] .

Experimental data allow to establish that energy spec-
tra of neutrons generated in a flare may be described as
power law in wide energy interval 50 to 1000 MeV with the
spectral indexes 3 and 3.5 for the flares 21.06.80 and
3.06.82 accordingly.

In contrast to γ-lines which are formed by low energy
particles(10-30MeV)neutrons contain an information on energy
spectra and angular distributions of accelerated particles
in wider energy interval. Calculations of charged-particle
energy spectra based on the observed neutron spectra have
been made by Ramaty et al. and by us [7-13].Ramaty et al.
considered thick-target model and assumed that in the inter-
action region the distribution of accelerated particles is
isotropic.They have also assumed that after their production
the neutrons escape freely from the Sun.But because the neu-
trons have mean free paths comparable to the stopping range
of the protons which produce them,the protons should be
trapped magnetically in the region at column depths signifi-
cantly less than their ranges.It was shown that both γ-line
and neutron experimental data might be explained if charged
particle spectrum is described by the Bessel function.

In our calculations we tried to refuse the assumption
on magnetic trap and considered a beam configuration of ac-
celerated particles.In this case for any direction of beam
the flux of solar neutrons increases with an increase of a
flare heliolongitude.It can be easy shown for the beam di-
rected to the observer.Really,the thickness of matter tra-
versed by accelerated particles in the solar atmosphere into
Earth's direction for limb flare is higher than for disc
flare about $(\pi R_\odot /2 h_o)^{1/2} \simeq$ 30-100 times (h_o - is the
scale height, R_o - is the solar radius). If the accelerated
particles move to the Sun the neutrons which are scattered
on 90° for the limb flare and on 180° for the disc flare are
detected.The probability of backscattering is less relative
to the scattering on 90°.However,as in this case nuclear re-
actions occur in deep regions of the solar atmosphere an ab-
sorption of neutrons may be essential.This effect was consi-
dered by us and it is shown that the limb retains an advan-
tage.

All calculations of neutron generation and their escape
from the Sun were made using Monte-Carlo method taking into
account the angular and energy characteristics of (PP) and
(pHe) reactions which are the main source of high energy
(>50 MeV) neutrons.The beams with different angles relative
to solar radius were considered.Particle spectra were pre -
sented as power law with different spectral indexes. For
different heliolongitudes total yield of neutrons and their
energy spectrum have been calculated.Fig.1 shows the depen-
dence of the fluxes of the neutrons (> 50 MeV) on flare he-
liolongitude for 3 cases. It is seen that for all cases the
neutron fluxes are decreased strongly from the limb to the
disk.If we consider the beam directed to the Sun the experi-
mental spectra for the flares 21.06.80 and 3.06.82   may be
explained if γ_p = 3-3.5 for E_p>100 MeV.In this case using
experimental figures for total flux of neutrons: $2.8 \cdot 10^{28}$ and
$2.5 \cdot 10^{29}$ we obtain for the total number of accelerated par-
ticles the following values: N_p(> 30)=$7 \cdot 10^{32}$ and $7,5 \cdot 10^{33}$,
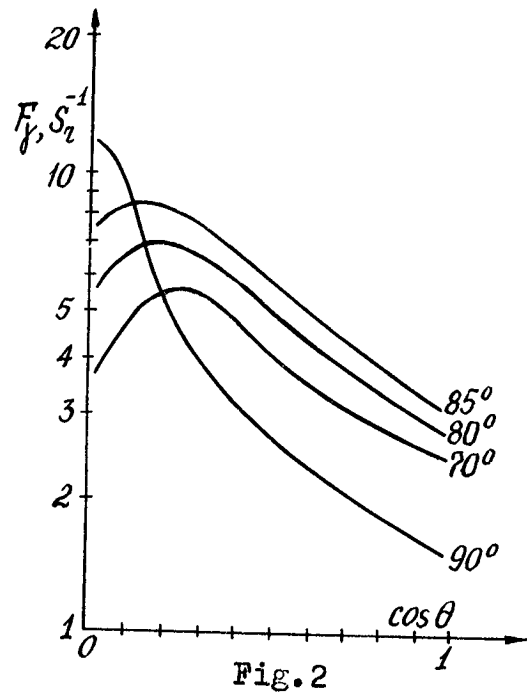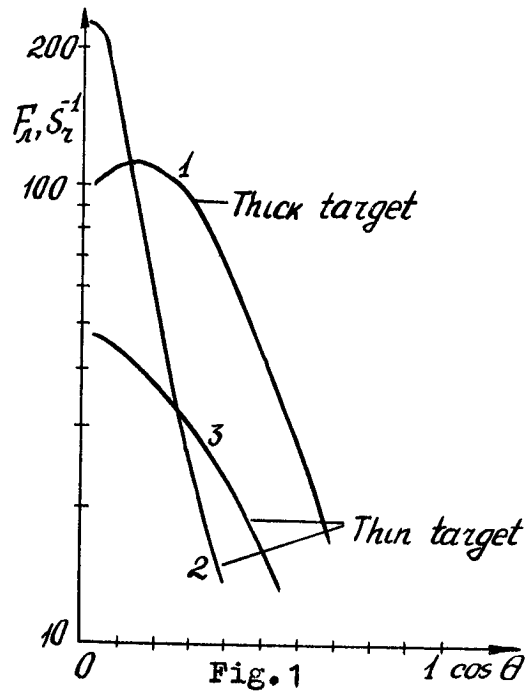
Dependence of neutron fluxes on
flare heliolongitude for the
beams with different angles re-
lative to solar radius.
1.$\alpha=0$, $\gamma_p=3,5$, $N_p(>30\text{MeV})=10^6$
2.$\alpha=90°$. 3.Isotropic yield to
upper hemisphere $\gamma_p = 2.5$,
 $n\,N_p(>30\ \text{MeV})\,h_p^{1/2} = 1.5\cdot10^{23}$, n
is number density in an interac-
tion region.

Dependence of gamma-ray
flux on flare heliolon-
gitude for beams with
different angles rela-
tive to solar radius.

accordingly.These figures are in good agreement with the to-
tal number of accelerated particles obtained by using γ-line
data (see [13] and references therein).So, supposing a beam
configuration it is possible to explain particle spectrum as
power law from 10 MeV to 1000 MeV with single spectral index.
Definitive conclusion can be made after obtaining of experi-
mental distribution on heliolongitude for flares with measu-
rable neutron fluxes.

Now we concern with the problem of high energy γ-rays.
At the present time 14 solar flares with high-energy
(> 10 MeV) γ-rays are registered [14].These events have a
strong solar limb preference with 13 of 14 occurring in fla-
res with a heliocentric angle >72° [14].

If high energy gamma-rays are generated by ultrarelati-

vistic electrons then the radiation is directed along of
electron velocity and above considered arguments are correct.
Let us consider the case when the source of high energy gam-
ma-rays are π^o-mesons,which are generated in the same reac-
tions as energetic solar neutrons.

It is seen (Fig.2)that the dependence for $\alpha < 90^o$ is
weaker than for the neutrons.For tangent beams an advantage
of limb is obvious.But in this case the flare should occur
in dense region n $\geqslant 10^{13}$cm^{-3}.According to [14] all high energy
γ-ray flares are characterized by fast impulses ($\leqslant 2s$)which
is in favour of high density of interaction region. Thus we
cannot exclude a nuclear origin of high energy γ-rays.To made
a definitive conclusion on the source of high-energy γ-rays
it is very important to measure an energy spectrum of gamma-
radiation.

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