THE EVALUATION OF THE HIGH-ENERGY PROTON RADIATION EFFECTS ON THE HUMAN BLOOD-FORMING ORGANS (BFO) WITH SELF-SHIELDING TAKEN INTO ACCOUNT

L.N.Smirenny, V.M.Petrov, A.V.Khortsev

Solar cosmic rays protons and radiation belts protons with the energies of more than 30 MeV are of the greatest hazard for the spaceship crew. These sourses of cosmic radiation form the irregular distribution of the depth doses in the body. The depth doses distribution depends on the spectrum of the protons. The best description of the spectra now is given in the form of

$$N(P) = N_0 e^{-P/P_0} \qquad (1)$$

where P_0 is a characteristic rigidity (MV). According to the estimate the dose at the depth of 5 cm of tissue is less as compared with the skin dose in the factor of 4-14 for the solar events with P_0 of 195 MV and 80 MV respectively. These depth dose distributions should be taken into consideration while estimating the irradiation doses on various human organs. The most difficult thing is to estimate the radiation effect on the blood-forming organs (BFO) as they are in various places of a human body. BFO have the highest radiosensitivity. One of the widely spread deseases is a BFO-form of the radiation sickness. So the BFO irradiation is the most important factor in the estimation of radiation hazard for a man.

The affection value of the BFO is determined by the irradiation dose. In case of dogs (3) this dependence is shown in fig. 1. To estimate the radiation hazard under the above-mentioned conditions it is necessary to establish the physical index describing the BFO affection in the best way.
According to the modern data an inaffected part of the BFO can help to reconstruct the functioning of the BFO system. Having assumed that the radiation affection doesn't depend on the position of the BFO cells and is determined only by their quantity, it is possible to estimate the BFO affection value with the help of an average number of the dead cells per unit of volume (5):

$$L = \frac{1}{V} \sum_{i=1}^{n} f(D_i) \Delta V_i \qquad (2)$$

where D_i - is the dose in the elementary volume ΔV, and n - is the number of these volumes, finding place in the total BFO volume.

Let's assume that the affection value of the human BFO is similar to the one shown in fig.1. Then this dependence can be described with the help of the linear function $f(D) = \kappa D$ in the range of up to 200 rads with an error of less than 20%. Based on this law we may rewrite equation (2):

$$L = \frac{\kappa}{V} \sum_{i=1}^{n} D_i \Delta V_i \qquad (3)$$

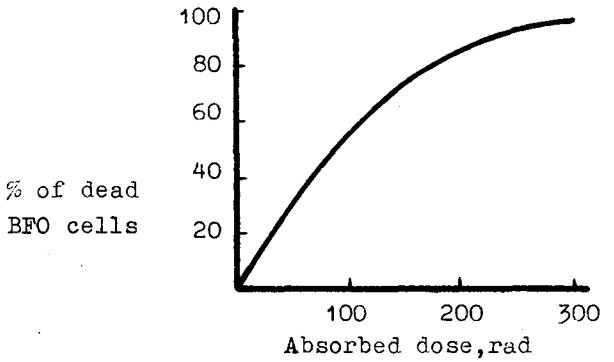

Fig.1 The dependence between the BFO affection and an irradiation dose for dogs

Thus, the irradiation effect may be characterized in this dose range with the help of the average dose for the total BFO.

$$D_{BFO} = \frac{1}{V}\sum_{i=1}^{n} D_i dV_i \qquad (4)$$

Let's note that the dose range is of the greatest interest as it includes the doses used at the reglumentation of the cosmonauts' irradiation (1).

The strongest hazard for the cosmonauts takes place when they work in the space suits or in the orbital moduls with the shield thickness of less than 1-2 $g \cdot cm^{-2}$. In this case one can assume that the radiation is isotropic. BFO doses were carried out for these conditions. It was assumed that the estimations of protons spectra have characteristic rigidity in the range of 80-195 MV.

Using the so called "straightahead model" (6) we may write the average dose on the BFO in the following way:

$$D_{BFO} = \frac{1}{4\pi V}\sum_{i=1}^{n} \Delta V_j \sum_{i=1}^{m} D(h_i)\Delta\omega_{ij} \qquad (5)$$

where is a solid angle in which the tissue thickness, shielding the elementary volume ΔV is h_i.

If we consider the value of ΔV to be constant then in this case $\Delta V/V$ is equal to $1/n$.
Assuming that the tissue thickness accounted into consideration differs in the values in proportion to Δh, we may rewrite equation 5 in the following way:

$$D_{BFO} = \frac{1}{4\pi n}\sum_{i=1}^{m} D(h_i)\sum_{j=1}^{n} d\omega_{ij} \qquad (6)$$

The value of $\Delta\omega_i^* = \frac{1}{n}\sum_{j=1}^{n}\Delta\omega_{ij}$ is an equivalent solid angle, corresponding to the tissue thickness of h_i. In these terms the equation (6) may be rewritten:

$$D_{BFO} = \frac{1}{4\pi n}\sum_{i=1}^{m} D(h_i)\Delta\omega_i^* \qquad (7)$$

Thus, for evaluating BFO doses it is necessary to find the dependence between and the tissue thickness.
For this purpose the shielding of 330 points in which BFO were placed, was calculated with the help of method (6). The dependence of $\Delta\omega^*$ (h_i) mean with respect to the whole body is shown in fig.2

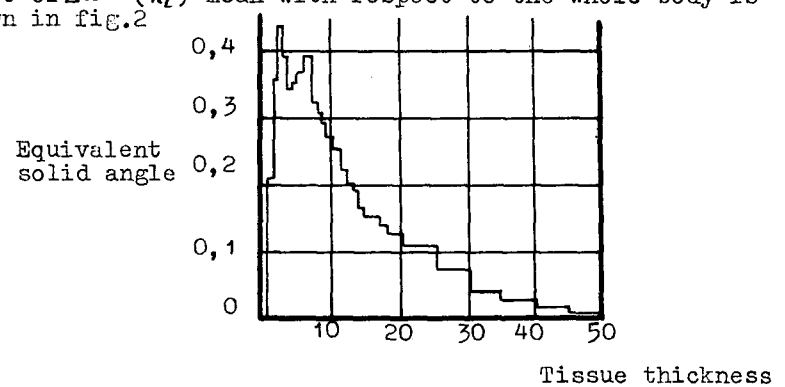

Fig.2 The dependence between the equivalent solid angle and the tissue thickness

The analysis of these data shows that the tissue thickness of less than 10 g·cm^{-2} is of the major importance while evaluating the average dose on the BFO.
The solid angle corresponding to these values of the shielding thickness is more than 50% of the total solid angle.
In this case the average BFO dose is formed by the primary radiation.
The evaluation of the dose part formed by the secondary radiation gives the value of 10-15% from the total dose.
BFO doses calculated in this way in case of solar cosmic rays, are given in the following table

Shielding thickness g·cm^{-2}		P_o MV			
		80	100	120	195
0	D_{BFO}, rad	41	45	47	52
	Z_{ef}, cm	4,5	5,0	5,5	7,0
0,5	D_{BFO}, rad	29	34	38	44
	Z_{ef}, cm	5,0	5,5	6,5	7,5
2,0	D_{BFO}, rad	20	21	24	33
	Z_{ef}, cm	5,5	6,5	7,5	8,5

The dose values D_{BFO} and the effective BFO shielding Z_{ef} in case of the solar cosmic rays with P_o =80-195 MV and N_o =10^9 cm^{-2}

The values of the effective BFO shielding were evaluated on the basis of the attenuation curves of the dose, when R_0 =80-195 MV and the shielding thickness is 0;0,5 and 2 g·cm^{-2}. d_{eff} values are given with the accuracy ± 0,3 cm.

The above-mentioned data show that the effective BFO shielding depends on the characteristic rigidity of spectrum.

Thus, radiation hazard evaluations may be incorrect as they are based on dose values only at the depth of 5 cm of tissue.

This approach to radiation hazard evaluation may be made more accurate in case of obtaining new data concerning the dependence between the BFO affection and an irradiation dose for a man.

REFERENCES

(1) Biological effect of the high-energy protons,Atomizdat, Moscow 1967
(2) Guskova A.K.,Baisogolov G.D.,Radiation sickness of a man, Meditsina,Moscow 1971
(3) Abramova G.M. e.a.,The Forecast of the biological effects at the irregular irradiation of dogs by high energy protons, in alm."Biological effects of irregular radiation influence",Atomizdat,M.,1974
(4) Jammet H.P. e.a., in "Radiation Protection",Proceedings of the First International Congress held in Rome, September 1966,part 2,ed.by W.S.Snyder,Pergamon Press, London-N.Y.-Paris,p.1249
(5) Keirim-Markus I.B.,Dosimetric index of the acute radiation effects,Medical Radiology,17,number 7,1972
(6) Dudkin V.E. e.a.,Investigation of the shielding boundaries influence on the dose field forming in case of charged particles,Moscow,MEPhI-1964
(7) Smirenny L.N.,Litvinova E.G.,Khortsev A.V.,Study of Spatial distribution of tissue doses with the aid of a phantom-mannequin III Intern.Congress IRPA Washington 1973.