SOME ASPECTS OF ACTIVE SHIELDING AGAINST THE RADIATION IN SPACE

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Active shielding based on the deflection of the charged particles by the electric and magnetic fields has recently attracted much attention. It is known that the possibility of the reduction in the weight of passive shielding is limited by nuclear-physical constants of the materials. At the same time the weight of the active sheidling is determined by technical characteristics of the materials and equipment, and decreased along with their improvement. Our results show that already now expected weight of active sheilding in a number of cases may be significantly less than the one of passive shielding.

In the active shielding it is necessary to take into account deflection of charged particles by the electric and magnetic fields as their interaction with the shell of vehicle, the magnetic system, etc. Introduction of the terms describing non-conservation forces essentially complicates the solution of the corresponding equations. First we consider electrostatic shielding, in which the charged particles are deflected from the compartment by the electric field. This field may be created either in the vacuum or in the dielectric medium. Such shielding requires electrostatic and light screening of the high potential electrodes.

The screens eliminate charge leakage caused by the plasma flows and photoelectric currents on the sunlight parts of the trajectory.

Some problems of electrostatic shielding against protons are discussed in References 2-3, in which are shown that even in the screened shielding the very small electron current (due to the electron emission etc.) creates the secondary radiation of high intensity. Additional technical difficulties render the concept of vacuum electrostatical proton shielding unreal.

The so-called plasma shielding[4)] offers some promise in this aspect. It possesses, however, its own principal drawbacks.

At the same time it is possible to create the effective electrostatic shielding against electrons of the natural and artificial radiation belts. Naturally it is necessary to have a shelter against solar flare protons[1,5)].

Calculation of shielding parameters involves determination of summary electron and bremsstrahlung dose-rate in the presence of the electric field. Fig. 1 shows (as an example) the results of dose-rate calculation versus thickness of the structural elements (electrodes, the shell of vehicle, etc.) for a different potential.

It is shown that the operational voltage values are in the range of 10^5-10^6 volt and essentially less than maximum electron energy of the radiation belts. Creation of the above voltages does not present substantial technical difficulties owing to the extremely small current in the shielding.

It is interesting that electron fluxes of high intensity may create deflecting electrical field by themselves and thus the high-volt source may be avoided.

The maximum dose values in the compartment obtained during charging of the shielding by the fluxes of belt electrons to operational voltage do not exceed 10^{-2}-10^{-1} rad. Self-charging therefore can be regarded not only in case of power failure but also as operational condition of electrostatic shielding.

Along with vacuum electrostatic shielding it is possible to create electrostatic dielectric shielding. The most interesting is the case when electric field originates as a result of irradiation of dielectric by the high energy particles stopped. In some dielectrics, decay time of captured charge is considerable[7)]. In this case, particle slowing-down occurs as a result of interaction not only with the material but also with the electric field. As an example, Fig. 2 gives calculation electron spectrum carried out by the Monte Carlo method together with V.F. Baranov.

It is evident that even moderate field strength essentially reduces particle penetration and consequently shield thickness.

The electric field in the dielectric also reduces bremsstrahlung yield. However, in the self-charging condition the doses are essentially higher than for vacuum shielding. Therefore such condition can be used only in some cases.

Magnetic shielding is based on deflection of charged particles from the compartment by the magnetic field. In most cases the magnetic field should be created by superconductive magnets; the advantage of superconductive magnets is not evident only for shielding against electrons.

In flight of relatively short duration superconduction state can be assured by helium store on board$^{1)}$. Whereas in long flight, low-temperature refrigerator facility is required. It is necessary to account for the attenuation of the particle flux in the magnetic system, the shell of vehicle etc. On the other hand, since after tha passage of the particle through the material its pulse becomes less than at the inlet, some particles may be captured by the magnetic field. Contribution of these captured particles into the radiation level is comparable by the order of magnitude to the contribution from other particles even if the average path through the protected object is considerably less than their range.

As an example, Fig. 3 gives the results of dose calculation for the phantom surrounded with the shell, which in its turn is in the magnetic field of the toroidal type. The curves are very unusual due to the fact that Bragg maximum is now on the phantom now in the shell. According to the calculations it requires a complete deflection of 50-100 MeV protons. Summary current of that system must be about 2.10^7 a. Equivalent thickness of the passive shielding is several times more than in the case of magnetic shielding (see Table 1).

Table 1

The absorbed doses D versus the summary thickness m_a of the active shielding (including superconductor, construction etc.) for cut-off energy E = 100 MeV and equivalent thickness of the spherical and cylindrical passive shield (m_s and m_c respectively) [1])

Spectrum	All solar flares during 1958-1960 years			Centre of the proton belt		
m_a, g/cm^2	m_s	m_c	D, rad	m_s	m_c	$\bar{D}$, mrad/sec
5	30	25	14	>30	>30	0.17
10	>30	30	11	>30	>30	0.15
15	>30	>30	8.5	$\gg30$	$\gg30$	0.11

Rem-doses of the galactic radiation were found by the methods described in Ref. 1. For the cut-off energy 320 MeV per nucleon (corresponds to the cut-off 1 GeV for protons) and summary thickness of phantom, shell etc. 60 g/cm^2 rem-doses are 4.10^{-3}; 7.10^{-3} and 2.10^{-2} mrem per nucleus for Z = 5; 7; 10.

Additional to the calculation methods some experimental methods for determination of active shielding efficiency have been developed. Use of low-energy electrons guns makes it possible to investigate the characteristics of the magnetic shielding on scale models (see also Ref. 7). In some cases it is more convenient to study the motion of charged particles in the magnetic shielding using analogue devices.

The results show that in many cases both electrostatic and magnetic shielding have an advantage over the equivalent passive shielding.

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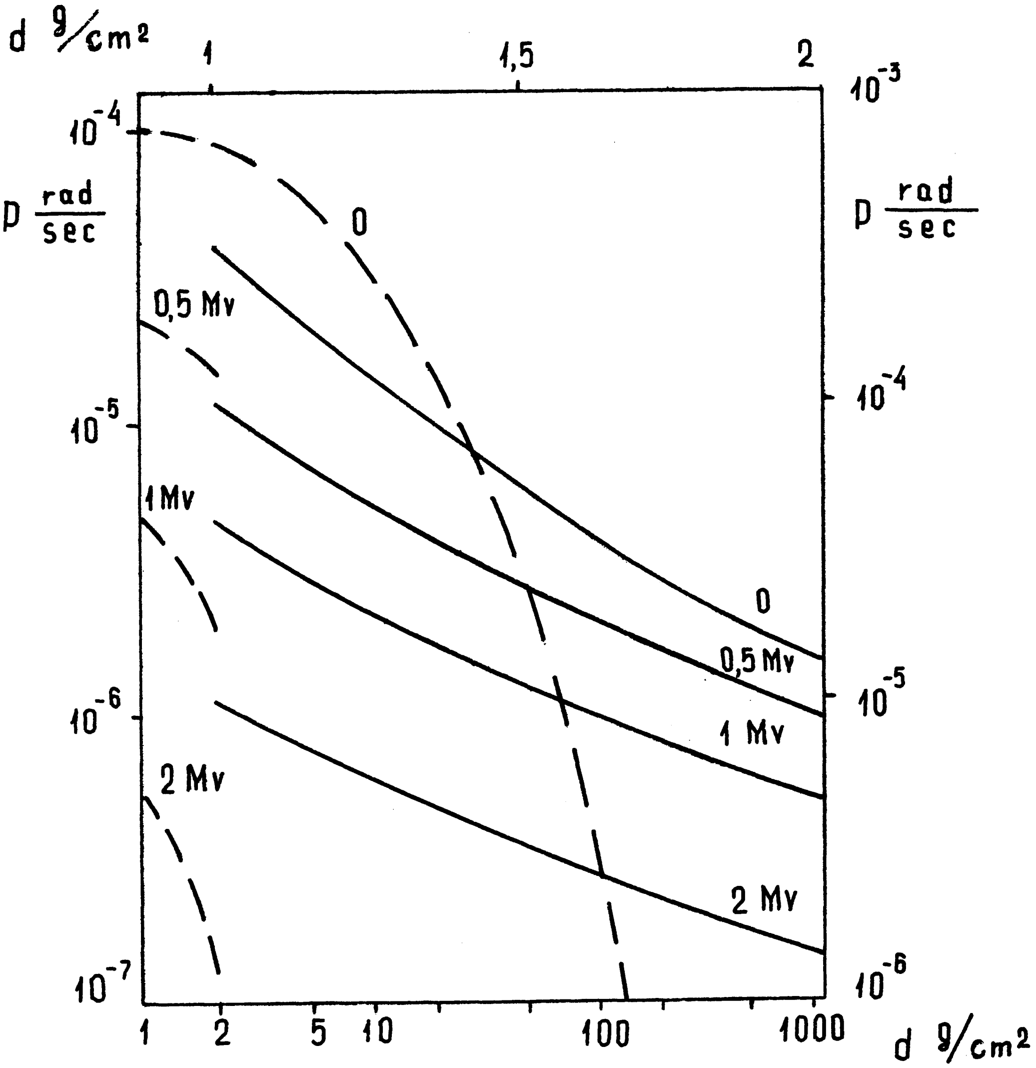

Fig. 1 Electron (dotted curves) and bremstrahlung (dashed curves) doses versus the depth for different voltage [the spectrum $exp\{-0.575\,E - 0.055\,E^2\}$, the electron flux $N_0 = 10^7$ electr/cm^{2}sec], Left and lower axises is related to the dotted curves.

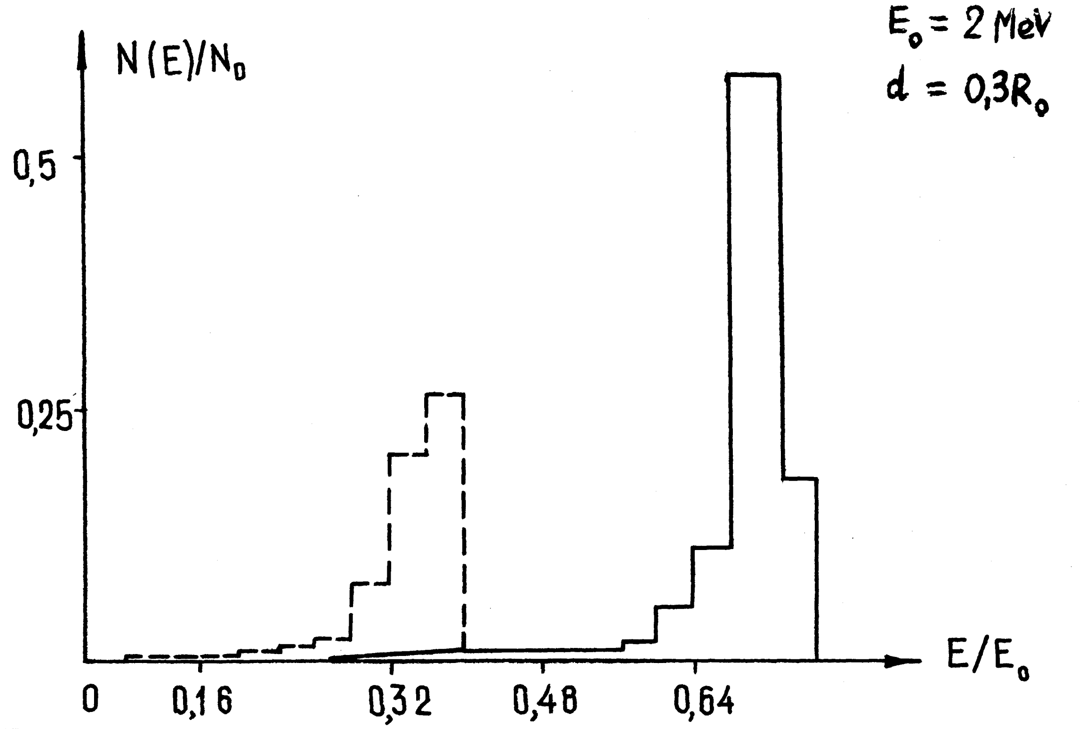

Fig. 2 Energy distributions of electrons which passed through the dielectric layer with electric field $\mathcal{E}=2\frac{Mv}{g/cm^2}$ (dotted histogram) and without it (dashed histogram).

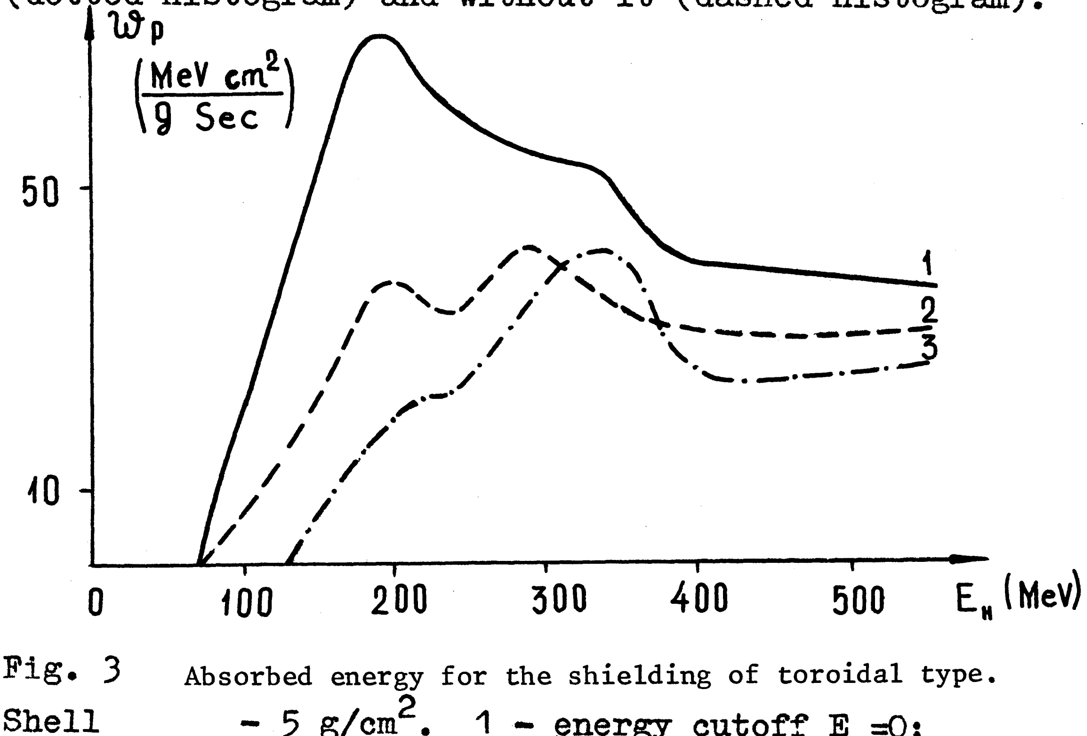

Fig. 3 Absorbed energy for the shielding of toroidal type. Shell - 5 g/cm^2. 1 - energy cutoff $E_0=0$; 2 - E_0 = 50 Mev; 3 - E_0 = 100 Mev.

DISCUSSION

Paper : Some aspects of active shielding against the radiation in space

MAEDA : I would like to know the power requirement for this type of shielding.

TRUKHANOV : The power depends on the type of magnetic system and its size. For example, for toroidal system the power of refrigerator is about 10-30 kwt, at inner radius of system about 2.5-3 m and its length about 10 m.

WIDERÖE : What is the field strength in the magnetic shielding?

TRUKHANOV : For the given cut-off energy E_o the field strength also depends on the type of magnetic system and its size. If $E_o = 50 - 100$ MeV and the magnetic system is as described in the previous answer, the field strength is about 30 - 20 kgauss.

GENERAL DISCUSSION ON SESSION 10

WILSON:

i) Do conventional QF developed for the protection of persons on Earth apply to those persons who leave the security of the Earth for the many potential hazards of space?

ii) Question to Dr Engelmann. What are the prospects for the prediction of solar proton flares, or the early warning of solar flare protons by the other emissions from the regions of solar activity?

ENGELMANN: Le soleil est surveillé par de nombreux observatoires, et les données sont rassemblées dans un centre mondial spécialisé. On arrive à se faire une idée des conditions des taches solaires permettant de prevoir une éruption; mais on ne peut encore prevoir le moment exact où l'éruption va se produire.

KOVALEV : I should like to make a few comments with respect to some papers presented today. I consider Dr. Prêtre's paper very interesting, especially as far as the practical aspect is concerned.

There are, in my opinion, at least two principal aspects of the radiation safety problem.

One aspect concerns occupational risks involved in medical, industrial and research uses of radiation and is covered by the ICRP recommendations. The other aspect lies practically outside the ICRP activity scope and includes radiation protection during space flights. In this field the conservative approaches criticized by Dr. Prêtre are especially expensive. For example, a 10% overestimation of the radiation hazard for a space craft with radiation shielding thickness in the range of 30 to 60 g/cm^2 designed for 2 to 3-year mission would result in about 1.5 tons weight penalty.

The imposed weight limitations explain the necessity for the highest degree of accuracy in establishing the justified risk doses used as crew radiation safety criteria during space missions. Obviously the justified risk dose value depends on space-flight conditions, mainly on its duration.

At present the recommended safety level for missions not exceeding 1 to 2 months is 15 rem. That means that the shielding of the space-craft command and service modules must reduce the total dose from galactic cosmic radiation, trapped radiation belts and other possible radiation sources, to no more than 15 rem for the whole mission duration.

For radiations of a stochastic nature, such as, for instance, solar radiation, the justified risk dose is used. The justified risk dose for the Earth orbital and lunar missions is 50 rem. It could be used as a criterium when designing a shield for the space-craft radiation shelter to protect the crew during large solar flares. Not only the received total dose must not exceed 50 rem but the risk of the excess should be minimized by the shielding. The meaning of this should be clear from the following comparison: the shield thickness for the radiation shelter with the 10% probability of solar proton flare dose exceeding 50 rem in 600 days is 30 g/cm^2 while the reduction of this probability to 1% would require almost doubling of the shield thickness.

It is then obvious that determination of the justified risk doses as well as the dose excess risk values to be used as design criteria for interplanetary space-craft radiation shielding is one of the most urgent tasks facing the space radiobiology and radiation shielding physics.

JENKINS : My remarks are to Dr. Kovalev's numbers of 15 rem per 30-60-day flights, or 50 rem per solar flare for the cosmonauts. This presupposes some active dosimetry (in addition to film badges, etc.), to allow the cosmonauts to determine when they are approaching these limits. Would you comment on this active dosimetry for your cosmonauts.

KOVALEV : The in-flight evaluation of the radiation environment by cosmonauts is done with onboard dosimeters performing the real-time monitoring of the accumulated doses and dose-rates. Ionization chambers are used as radiation detectors. The transition from measured absorbed dose values to dose equivalents is done by means of effective radiation quality coefficients specified for each type of space flight. For orbital flights, for instance, the effective quality coefficient is from 1.2 to 1.4, for lunar flights it is about 1.5. The on-board dosimeters have warning signals and along with the ground based radiation environment control system and dosimetric equipment installed aboard the artificial satellites, provide timely warning of the crew concerning the necessity of taking radiation protection measures.

KIEFER: This is a remark concerning the general questions raised and particularly Dr Kovalev's paper. I appreciate that the considerations have to be different for astronauts from those for people exposed to "normal" occupational risk. We have to decide what kind of risk we are considering, and for humans this is definitely not the survival within 30 days (except perhaps in the application of nuclear weapons). We do not have sufficient data for mutation and disease induction; mice survival curves appear to be entirely useless for the estimation of QF for protection purposes. As long as we do not know better values for low dose exposures and long term effects we have to assume the highest value of the QF which has been found in any experiment. Protection has always to be conservative, even over-conservative.