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One of the approaches to calculating the shielding properties of equipment and devices aboard spacecraft with respect to cosmic radiations consists in the assumption of a random arrangement of matter in the equipment, which is characterized by certain distribution functions. In the present study, mass-thickness distribution functions were obtained experimentally by means of gamma-radiation thickness measurements both in plane geometry for equipment units, and in spherical geometry with respect to given points within the spacecraft. /1*

In both cases gamma radiation which passed through a section of equipment was registered by a collimated scintillation detector with Compton-scattering pulse height discrimination. In plane geometry the collimated beam of gamma quanta with a square cross-section of 1 x 1 cm was coaxial with the collimator of the detector, while the piece of equipment under test was discretely moved with the aid of a scanning stand in order to examine successively all adjacent sections of the surface.

Measurements of the thickness distribution of equipment shielding a certain point within the spacecraft were made with the following arrangement [2]: An isotropic gamma source was placed at a given point within the spacecraft, and the unscattered radiation passing through the equipment was picked up by a collimated detector with a NaI(Tl) crystal which could be moved outside the object by a coordinate system over a spherical surface with its

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* Numbers in the margin indicate pagination in the foreign text.

center at the given point.

When the detector was moved continuously through the azimuth angle ψ (within prescribed limits) [illegible] of the detector for /2
a fixed time $\Delta\tau$. The periodicity of such measurements was chosen such that in a corresponding time interval $\Delta t \gg \Delta\tau$ the detector was moved in the azimuth plane by the angular dimension of the rectangular collimator $\Delta\psi_o$ (see Fig. 1). When the detector reached the limiting angle ψ, the measurements were stopped, and the detector was moved in the polar plane by the angular dimension of the collimator $\Delta\theta$, after which the measurement cycle was continued by moving the detector through ψ in the opposite direction. The automatic change in the value of $\Delta\psi$ according to the law $\Delta\psi = \Delta\psi_o/\sin\theta$ allowed the results of individual measurements to be assigned to the sections of the surface under test which are adjacent to each other and subtend equal solid angles $\Delta\Omega = \Delta\psi_o\Delta\theta$ (where $\theta = 90° \Delta\psi = \Delta\psi_o$).

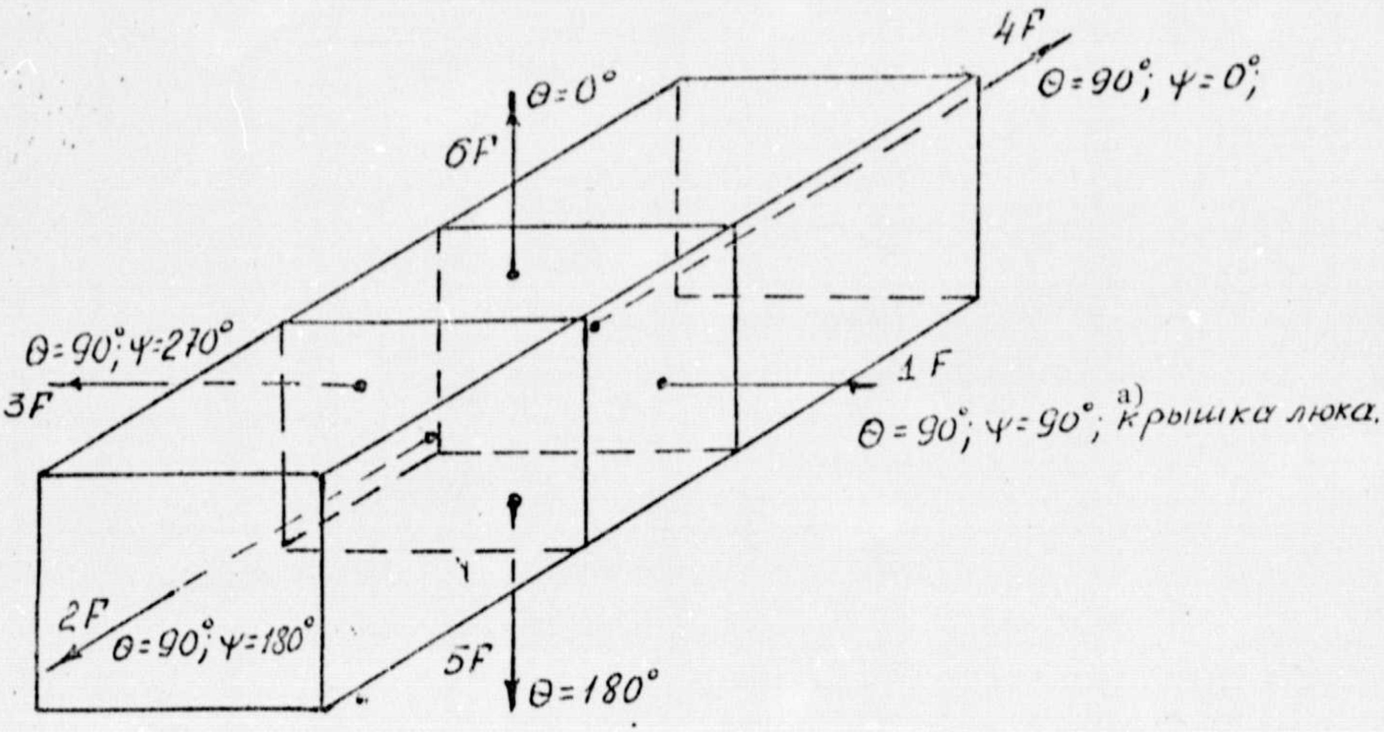

Fig. 1. Geometry of measurements
Key: a. Hatch lid

The distribution of the number of sections examined by the number of pulses was transformed in both cases into a distribution by thickness based on the calibration of the detector for standard thicknesses. The main source of error in spherical geometry is the recording of radiation scattered by sections of equipment adjacent to the section under test. This can introduce an error of up to 10%. However, a calibration curve was employed which gave the radiation intensity as a function of standard thickness, obtained in the presence of a scattering layer of known thickness.

Thus, if a calibration curve with a scattering layer of 5 g/cm^2 is used, then thickness measurements in the range of 1 to 10 g/cm^2 at the thickness of the scattering layer (which is practically equal to the minimum thickness of spacecraft equipment) lead to an error of $\pm$ 0.25 g/cm^2. Other sources of error in spherical geometry are associated with movement of the detector during measurements, and the overlapping of the sections under test and the spaces between them. These errors amount to 6% and do not lead to a distortion of the distribution itself. On the whole, the thickness-measurement errors amounted to $\pm$ 0.3 g/cm^2 at a thickness of 1-2 g/cm^2, and $\pm$ 0.5-0.6 g/cm^2 at a thickness of 10-15 g/cm^2.

The scanning stand was used to study the mass-thickness distributions in a total of 16 radioelectronic units of varying function, design and composition. The results of the measurements were smoothed by means of the Reyleigh distribution law:

$$f(x,z)=\left[1-C(z)\right]\frac{x-\gamma(z)}{\eta^2(z)}\exp-\left[\frac{x-\gamma(z)}{\sqrt{2}\,\eta(z)}\right]^2 \qquad (1)$$

where f(x,z) is the probability density of the thickness distribution for the geometric dimension z cm, x = g/cm^2; η,γ are /3 distribution parameters, where γ defines the minimum constant thickness in the equipment unit; $x \geq \gamma$; and $c(z)$ is the probability of having a constant thickness in the geometric dimension.

Smoothing of experimental results by the Reyleigh law was done by the method of least squares.

The mean thickness and dispersion values were obtained for three geometric dimensions in each unit, as well as the values of the parameters γ and η associated with them. Analysis of the results showed that these units can be divided into three main groups according to the character of the mass-thickness distribution (see Table 1), while the values of the distribution parameters could be related to the thickness in the unit in g/cm^2, defined as the product of the mean unit density $\bar{\rho}$ by the geometric thickness. Analysis showed that the mean value of the distribution $\bar{x}$ and dispersion δx^2 of the units examined are related by the expression

$$\frac{\delta x^2(z)}{\bar{x}(z)} = \text{const.} \qquad (2)$$

This equation indicates that the thickness distribution law is stable. However, the Reyleigh distribution law used by us cannot be considered stable. This discrepancy stems from the fact that as the mean thickness of the unit increases, the experimentally-measured distribution can be smoothed by both the Reyleigh law and the normal law, since the preexponential factor in expression (1) changes much more slowly than the exponential factor corresponding to the normal law. In other words, the experimental distribution laws can also be smoothed by the normal law, but this results in marked deviations from experimental values in the range of small thicknesses.

The $f(x,z)$ functions obtained were used to test the possibility of calculating the mass-thickness distribution function over solid angles $dx/d\Omega$ with respect to an arbitrary point in the spacecraft, assuming the distribution function of geometric dimensions over solid angles $dz/d\Omega$ is known.

The gamma thickness-measuring apparatus was used to measure experimentally the distribution $dx/d\Omega$ with respect to the points of location of the K-206 and S-1 detectors [1] in the Kosmos-936 spacecraft. The results of the measurements are presented in Fig. 2. The distribution function for these points was calculated by convolution of the distribution law of geometric dimensions over solid angles $dz/d\Omega$ with respect to selected points within the sphere and the Reyleigh law $f(x,z)$ according to the formula /4

$$\frac{dx}{d\Omega} = \int_{z_{min}}^{z_{max}} f(x,z)\frac{dz}{d\Omega}\cdot dz \qquad (3)$$

where $$\frac{dz}{d\Omega} = \frac{1}{2T}\left(1 + \frac{R^2 - T^2}{z^2}\right),$$

R is the radius of the sphere (R = 100 cm), and T is the distance from the point investigated to the center of the sphere (T = 70 cm, 90 cm).

Two variants of the parameters of the function $f(x,z)$ were examined in the calculation: the first, $\delta x^2/\bar{x}$ = 0.8 g/cm^2; the second, $\delta x^2/\bar{x}$ = 5.8 g/cm^2, where $\bar{x} = 0.7\,\rho z$ and ρ = 0.5 g/cm^2 for both variants. The results of the calculations are also given in Fig. 2. As can be seen, the calculation with $\delta x^2/\bar{x}$ = 0.8 g/cm^2 agrees well with experimental results, while the results of the calculation with $\delta x^2/\bar{x}$ = 5.8 g/cm^2 differ considerably from experimental data, thus indicating the strong influence of the relation $\delta x^2/\bar{x}$.

The agreement between the results of the calculations and experimental results in the case where $\delta x^2/\bar{x} = 0.8$ g/cm^2 suggests a method for determining the $dx/d\Omega$ distribution function with respect to an arbitrary point in the spacecraft based on the experimentally-derived distribution functions $f(x,z)$ for 2-3 points within the craft. To do this, solving the problem which is the inverse of (3), it is necessary to find the parameters of the distribution function $f(x,z)$ and their dependence on geometric dimension, and then calculate the required distribution according to formula (3). /5

In conclusion it must be noted that for many problems it is necessary to know the thickness of the material shielding a certain point in the spacecraft in all directions, rather than the distribution of thicknesses. Such results can be obtained only with apparatus for performing gamma thickness measurements.

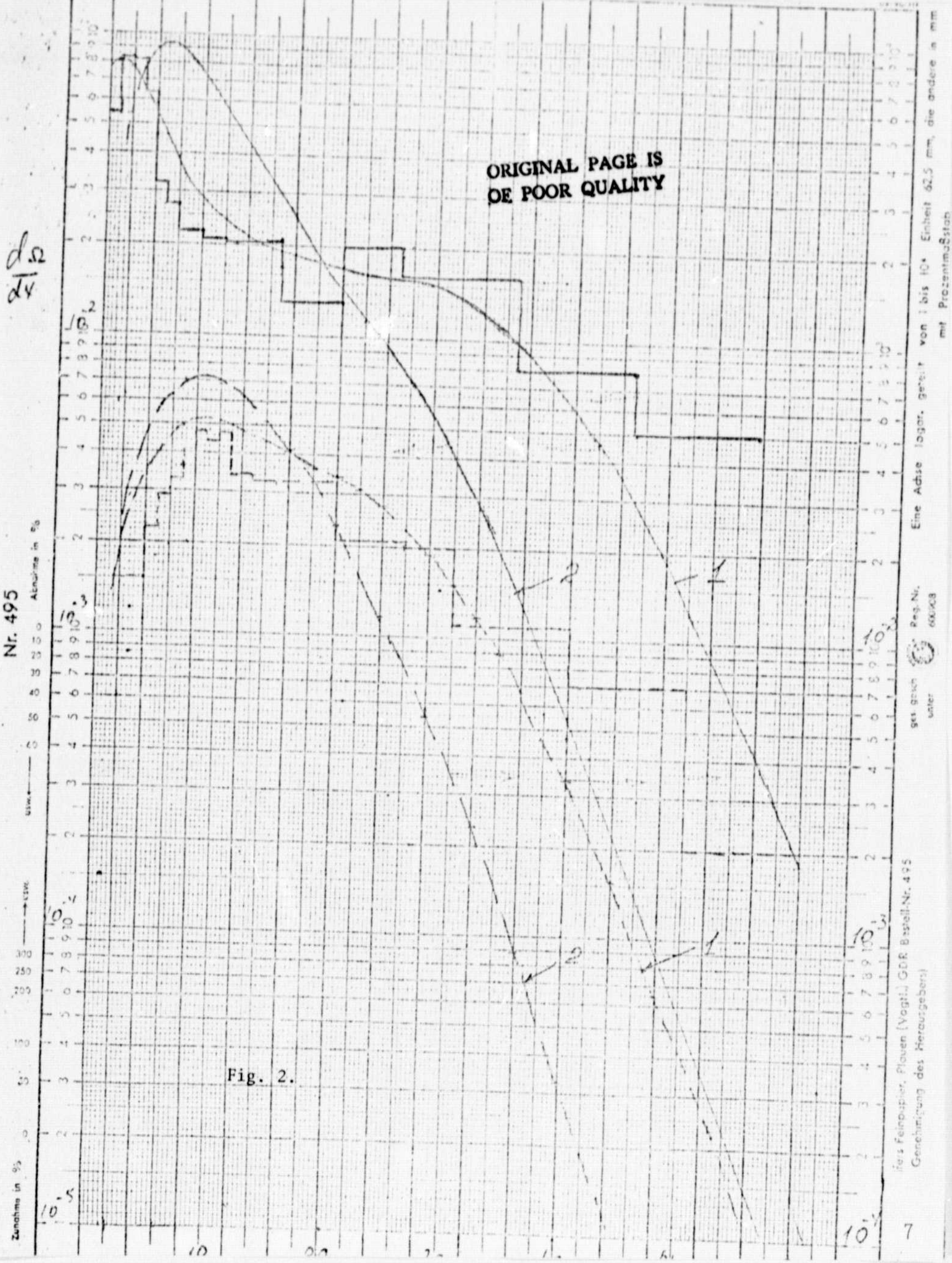

Fig. 2.

Table 1. Thickness Distribution over Facets for K-206

a) № грани	θ^0	ψ^0	b) δ г/см^2
1	90	90	8.5
2	90	180	11.0
3	90	270	22.0
4	90	0	55.0
5	180^0	-	20.0
6	0^0	-	6.0

c) Грань 1F направлена перпендикулярно к крышке люка.

Key: a. Facet no. b. δ g/cm^2 c. Facet 1F is directed perpendicular to hatch lid.

Table 2. Distribution of Solid Angles by Thicknesses for K-206

θ^0	ψ^0	a) δ г/см^2	$\Delta\Omega$ b) стерад
0-40	0-180	5-7	0.79
0-40	180-360	> 10	0.78
40-140	0-180	8-12	4.36
40-140	180-360	12-20	4.36
140-180	0-360	> 20	2.28

Key: a. δ g/cm^2 b. steradians

Table 3. Thickness Distribution over Facets for K-206

No. F	$\theta°$	$\psi°$	a) δ г/см^2
7 ~~1~~ F*)	90	0	8.5
8 ~~2~~ F	90	90	16.5
9 ~~3~~ F	90	180	30
10 ~~4~~ F	90	270	23
12 6 F	0	–	6
11 5 F	180	–	> 20

b) 7F Грань ~~1F~~ направлена к крышке люка.

Key: a. δ g/cm^2 b. Facet 7F is directed toward the hatch lid.

Table 4. Distribution of Solid Angles by Thicknesses for K-206 in the Range $40° \leq \theta \leq 140°$ $0° \leq \psi \leq 360°$

a) №	b) г/см^2	c) стерад
I	5,0-5,5	0,075
2	5,5-6,0	0,14[illegible]
3.	6,0-6,5	0,I77
4.	6,5-7,0	0,279
5	7,0-7,5	0,337
6	7,5-8,0	0,367
7	8,0-8,6	0,370
8	8,6-9,2	0,337
9	9,2-9,8	0,286
I0	9,8-I0,4	0,266
II	I0,4-II,0	0,258
I2	II,0-II,6	0,228
I3	II,6-I2,2	0,I90
I4	I2,2-I3,0	0,I67
I5	I3,0-I3,8	0,I57
I6	I3,8-I4,6	0,I68
I7	I4,6-I5,4	0,I69
I8	I5,4-I6,2	0,I56
I9	I6,2-I7,3	0,I45
20	I7,3-I8,3	0,I46
2I	I8,3-I9,4	0,I53
22	I9,4-20,5	0,I49
23	20,5-2I,6	0,I56
24	2I,6-22,7	0,I57
25	22,7-24,3	0,23I
26	24,3-25,9	0,256
27	25,9-27,5	0,264
28	27,5-29,7	0,3I9
29	29,7-32,4	0,377
30	32,4-35,I	0,353
3I	35,I-37,8	0,3I7
32	37,8-4I,9	0,323
33	4I,9-45,9	0,360
34	45,9-52,6	0,330

Key:

a. No.
b. g/cm^2
c. steradians

Note: Commas in tabulated material are equivalent to decimal points.