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A GAMMA-RAY TESTING TECHNIQUE FOR SPACECRAFT

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16. Abstract The article discusses to what degree cosmic radiation weakens the equipment and structure of spacecraft. The effect of the apparatus set-up is measured by gamma-ray testing and measurement of thickness of the equipment. The principle of the use of gamma-ray testing for this purpose is discussed. A drawing of the testing set-up is included. Measurement error with this method is also discussed.					
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A GAMMA-RAY TESTING TECHNIQUE FOR SPACECRAFT

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In a number of practical problems it is important to know to what degree cosmic radiation, for example, protons of solar flares and radiation bands of Earth, weaken equipment and structures of spacecraft. This involves interpretation of the readings of cosmic radiation detectors and the results of radiobiological experiments in space, calculation of the protection of equipment and radiation-sensitive materials [1--3]. For solving these problems, it is necessary to have the distribution of solid angles relative to a given point inside the apparatus according to the thickness of the material of the equipment $d\Omega/d\delta$ [4]. The distribution of $d\Omega/d\delta$ is obtained both for the design distribution of the mass of the spacecraft [5, 6], and experimentally by a method of gamma-ray testing in conjunction with an EVM [Elektronnaya vychislitel'naya mashina, electronic computer] [7]. This work elucidates the principle of the effect of the set-up based on gamma-ray testing and the method of measurement using distribution of the thickness of the equipment of the spacecraft with dimensions less than 5 m and thickness less than 50 g/cm² (Figure 1). The possibility of calculating passage of protons through a substance as a result of gamma-ray testing is explained by the fact that for a substance with an atomic number $Z < 30$ (basic design materials of the spacecraft [4]) weakening of gamma radiation with energy 0.5--1.5 MeV and loss of energy by the protons hardly depends at all on Z and is determined only by the density of the electrons on the radiation path [4, 8]. Determination of the thickness of the equipment is

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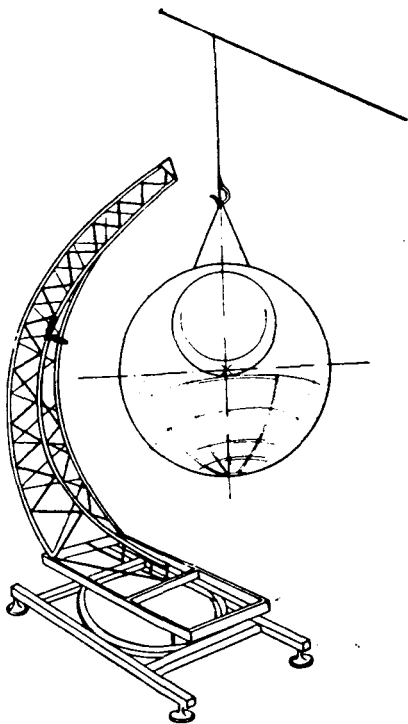


Figure 1. Overall view of the set-up for gamma-ray testing.

based on a comparison of the intensity of gamma radiation passing through the equipment and the intensity without it. The principle of the effect of the set-up involves the fact that an isotropic gamma source is located at a given point within the equipment and recording of unscattered radiation is conducted by a collimated scintillation detector moving outside the object of the coordinate system along a spherical surface with the center at a given point.

During continuous shifting of the detector along the azimuthal angle ϕ (in prescribed limits from ϕ_1 to ϕ_2) the number of pulses of the detector is measured periodically for a fixed time $\Delta\tau$. The periodicity of such units of measurement are prescribed so that for the corresponding time interval Δt , the detector was shifted

for an angular measure of square-wave collimator $\Delta\phi$ relative to the polar axis. Then, the condition $\Delta\tau \ll \Delta t$ is observed. When the detector reaches the position ϕ_1 or ϕ_2 , the measurements are stopped and shifting of the detector occurs along the polar angle on the angled measurement of the collimator $\Delta\theta$; after this, the cycle of measurement is continued with movement along the ϕ angle in the opposite direction. The change in size of $\Delta\phi$ according to the principle $\Delta\phi = \Delta\phi_0 / \sin \theta$ which in the set-up occurs automatically, makes it possible to record the results of single measurements on sections of the surface of the equipment lying next to each other and which secure uniform solid angles $\Delta\omega = \Delta\phi_0 \cdot \Delta\theta$, where $\Delta\phi_0 = \Delta\phi$ when $\theta = 90^\circ$.

Distribution of the number of single measurements according to the number of pulses in the measurements is transformed into distribution of solid angles according to thickness on the basis of graduations of the detector for standards of thickness.

The method of measurement and the required precision are determined by utilization of results. In the case of calculating the portion of protons of solar flares and radiation bands of Earth, a radiation method is used [4] and the expression for the portion has the form:

$$D = \frac{\Phi}{4\pi} \int K(\delta) \frac{d\Omega}{d\delta} d\delta,$$

where Φ --is the flow of incident radiation, $K(\delta)$ --is the function of weakening the dose for a single flow of protons depending on their spectrum.

In practice, they compute $D = \frac{\Phi}{4\pi} \sum_{i=1}^n K(\delta_i) \Delta\Omega(\delta_i)$, where /492
 $\Delta\Omega(\delta_i) = \sum_{j=1}^m \Delta\omega(\delta_{ij})$ and the smaller the solid angle of a single measurement of $\Delta\omega$, the more detailed is the nonuniformity of distribution of the material of the equipment calculated. When there is a limitation on the activity of the gamma source and at a prescribed statistical precision of unit measurements, the total length of the measurement in limits of 4π is proportional to $\Delta\omega^{-2}$ so that the technical solution is a compromise between the reading sizes. With the given arrangement, the radius of the spherical surface $R = 3$ m, the dimensions of the collimator aperture of the detector amounts to 2.1×3 cm, that is, $\Delta\omega = 0.7 \cdot 10^{-4}$ steradians, the source Cs^{137} radioactivity $50 \text{ mg} \cdot \text{equiv. Ra}$, $\Delta\tau = 0.07$ s and the corresponding length of measurement in the solid angle is 4π -30 hours.

Considering the form of $K(\delta)$ [3, 4] and the form of distribution $\Delta\Omega$ [1, 2, 4], one can state that the error of calculated values of the dose basically involves error in measurement of small thicknesses. With the indicated technical parameters of the arrangement, statistical error of unit measurement of

thickness 1 g/cm^2 amounts to $\approx 5\%$. However, statistical error of measurement of distribution of $\Delta\Omega$ can be decreased by methods which are used when processing equipment of the gamma spectra [9].

Another source of error is recording radiation scattered by sections of the equipment adjoining those considered. In spite of positioning the detector in a collimator and the use of amplitude discrimination of pulses, the accumulation of the indicated scattered radiation can reach 10%.

However, as the calibration one can use the relationship of the detector readings to the standardized thickness obtained with the presence of a scattered layer. In this case, the error will change the size depending on the actual thickness of the sections adjoining those being considered. Selection of thickness of the scattered layer is determined by the minimum thickness of the equipment. For example, with minimum thickness 1 g/cm^2 , the use of a scattered layer 5 g/cm^2 results in an error of $\pm 0.25 \text{ g/cm}^2$ in the range of measured thicknesses $1--10 \text{ g/cm}^2$.

Error, caused by nonuniformity of thickness within the limits of the section considered and shifting of the detector in time for a single measurement, can be estimated knowing the character of distribution of nonuniformity or after obtaining distribution of $\Delta\Omega$. The span of sections considered and spaces between them can be sources of error in the described arrangement; they amount to $\approx 6\%$ and cause hardly any distortion of distribution. On the whole, measurement error of thickness amounts to $\pm 0.3 \text{ g/cm}^2$ with thickness 1 g/cm^2 and $\pm 0.5 \text{ g/cm}^2$ when the thickness is 10 g/cm^2 . The simplest methods of increasing precision of measurements is increasing their duration. Using the indicated arrangement, distribution of thicknesses for a number of spacecraft were obtained. As an example, Figure 2 shows distribution of thicknesses of a Kosmos-690 biosputnik for points distributed in the area where animals are located [10].

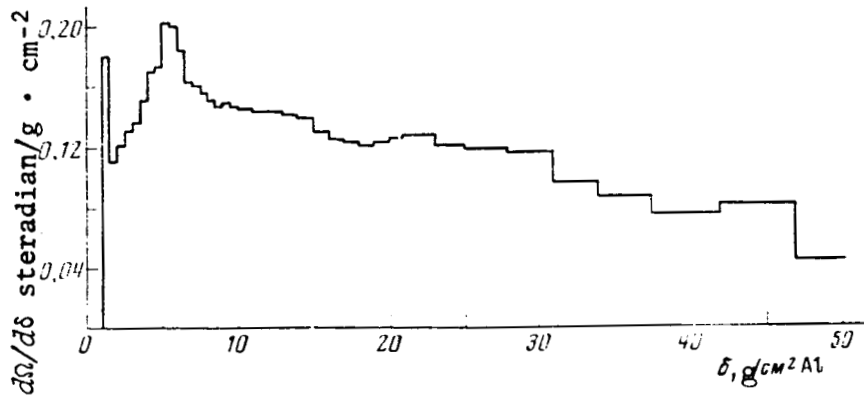


Figure 2. Differential distribution of solid angles according to thickness.