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by

A. A. Vorob'ev, V. A. Vorob'ev, et al.

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Production and Absorption of Braking Radiation with Maximal Energy 5-1000 Mev in Alkali-halide Crystals

by

A.A. Vorob'ev, V.A. Vorob'ev, E.K. Zavadovskaya, G.P. Sokolov and A.V. Pushkin

The pratical utilization of sources of braking radiation in radiation physics and radio-physical technology demands a knowledge of the amount of radiation absorbed due to the occurence of crystal defects. In order to compare and correlate the alterations in the properties of irradiated materials with the qualitative and quantitative characteristics of a beam of radiation it is necessary to know the distribution of absorbed energy, and the spectral distribution of the primary and secondary quanta and particles in each element of the irradiated specimen [1-3,5].

We have conducted an investigation of the production and absorption of braking radiation with maximal energy in the range 5-1000 Mev in crystals of potassium chloride, iodide, and bromide, sodium chloride, lithium flouride in specimens of aluminum, iron, copper, and lead.

For braking radiation of maximal energy up to 50 Mev a program was worked out to calculate, by a method of statistical testing, the spectral composition of the primary and secondary radiation, the coefficients of attenuation and absorption, and the energy accumulation and absorption factors.

The program we used in our work allowed us to calculate from one batch of raw data all the above parameters for thicknesses of the absorber up to 10-15 times the mean free path of the quanta. In this form the program is original, and saves significant amounts of time in complex investigations, including the calculation of various parameters of the radiation field.

This program allows us to compute, simultaneously, the build-up factors, the coefficients of attenuation, the mean energy of the spectral quanta, the spectral distribution of the primary and the scattered radiation fluxes, the distribution of the absorbed energy, and the signal-noise ratio, all normalized to the case of incident radiation at 1Mev/cm^2-sec. Calculations are in progress for the case of barrier radiation from external sources with a random energetic spectrum, with acylindrically symmetric field, for five radiation field of various characteristics, and of various dimensions [4]. This program allows one to do calculations for barriers of various materials and thickness, up to 20 mean free paths.

This program is executed segmentally, and all results are normalized as stated above.

Experimental investigations were conducted with the aid of X-ray film, ionization chambers, scintillation counters, and calorimeters; these were used to measure various parameters of the absorbed radiation. We created a specialized unit out of a calimeter and a thick-walled ionization chamber, which may be adapted for absolute measurement of the dose rate, and for the calibration of the X-ray film, and a thin-walled ionization chamber, which is used for relative measurements.

The following results were obtained in our investigations.

The distribution of the absorbed energy verus the depth of the barrier in the whole range of braking radiation energies 5-1000 Mev is described by a transition curve, with a maximum. The slopes of the rising and falling sides of the experimental curves decrease with the growth of the maximal energy of the braking radiation and with the reduction of the effective atomic number and density of the barrier material /Fig.1 a,b, and Fig.2/.

An increase in the effective atomic number of the absorber material leads to the fact that the depth at which the maximum of the depth-distribution of the absorbed energy /DDAE/ occurs is reduced /Fig.3 b/. The relationship between the depth at which half-maximum occurs vs. the maximal energy is displayed in /Fig.4a/, and vs. the effective atomic number in /Fig.4b/; these are analogous to the corresponding relations for the /DDAE/ in /Fig.3 a,b/.

The dose at the surface of the specimen, irradiated by the braking radiation decreases with the growth of the maximal energy of the braking radiation /Fig.5a/, and grows with the increase of the effective atomic number of the absorber material /Fig.5b/.

The absorption of the energy of the braking radiation, after the beam passes through the barrier, with the growth of E_{max}, up to 30-40 Mev, decreases, owing to the decrease of Compton scattering. In the range $E_{max} > 100$ Mev, this scattering again increases, due to the development of an electron-photon cascade /Fig.6 a,b/.

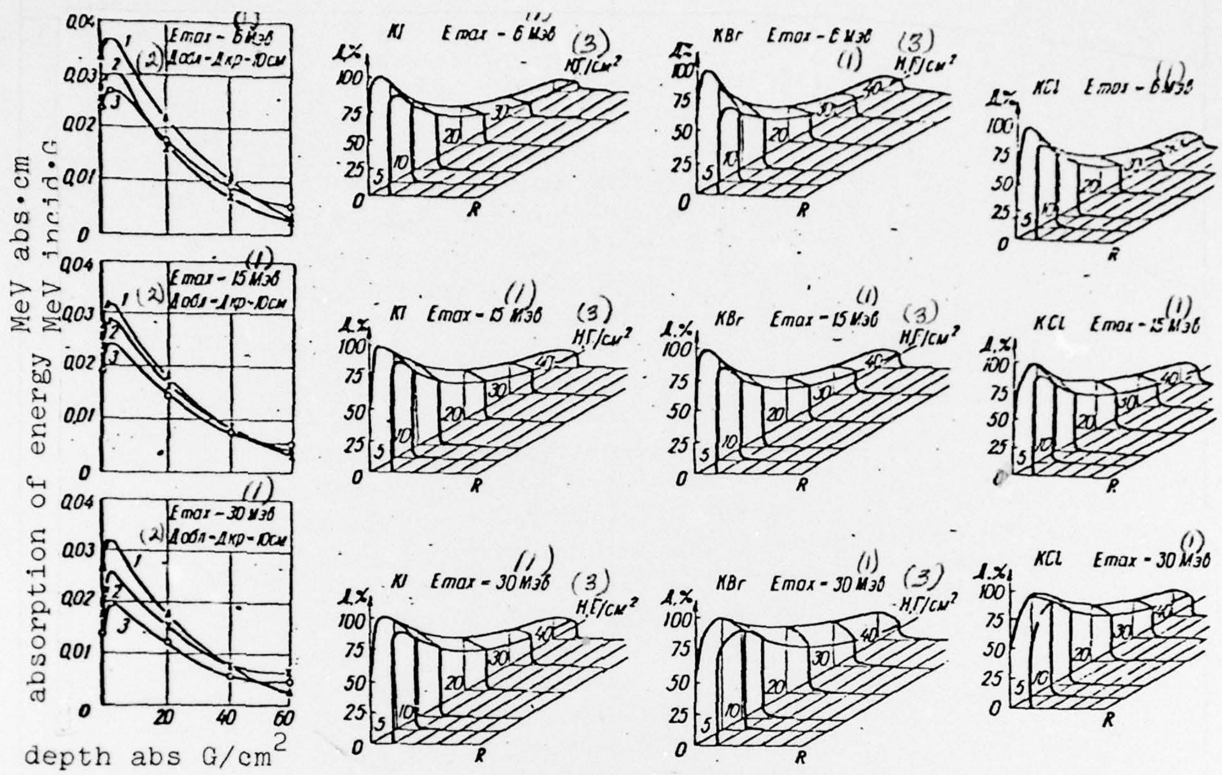

Figure 1. Depth (a) and Volume (b) Distributions of Absorbed Energy: Curve 1 - KJ, 2 - KB, 3 - KCl KEY: (1) Мэв = MeV; (2) Добл-Дкр = $D_{irr}=D_{cr}=10$; (3) НГ/cm^2= NG/cm^2.

The variations in the flux of the braking radiation, as it passes through the barrier, with the maximal energy in the range 5-30 MeV, have a common character. As the thickness of the barrier increases radiation fluxes are formed, the spectral composition of which, under further increase in absorber thickness, change little. The relationships of the average energy of the braking spectrum and the coefficient of attenuation with the increase of absorber thickness, are described by curves which tend toward saturation, which occurs at a thickness somewhat more than double that of the thickness at which the half-maximum occurs (Figure 7).

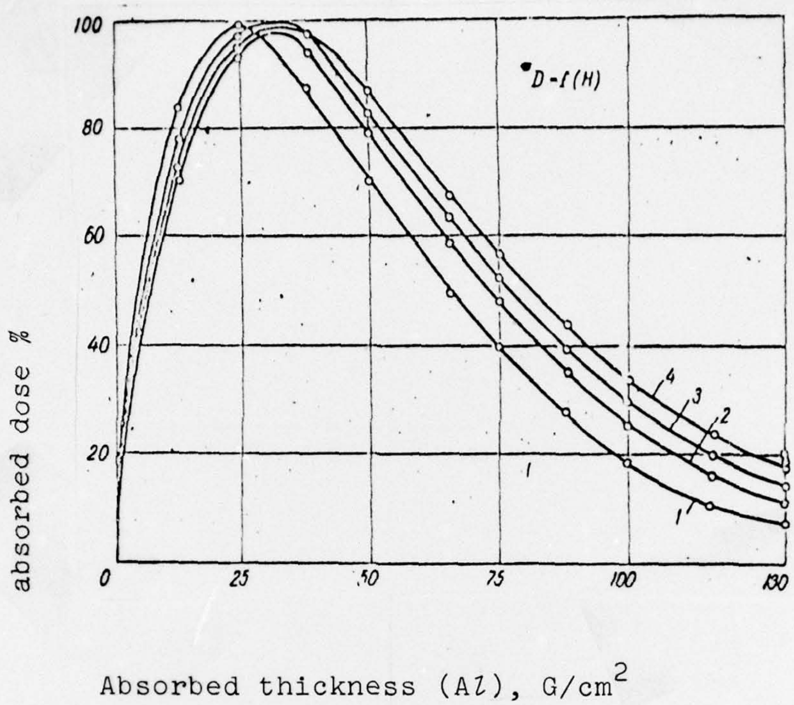

Figure 2. Depth distribution of Absorbed Energy in Aluminum curve 1 - 250 MeV; 2 - 500 MeV; 3 - 750 MeV; 4 - 1000 MeV.

As the beam cross-section is increased the build-up factor also increases, and an insignificant variation in the attenuation factor also occurs. With the beam diameter greater than 20 cm the value of the buildup factor, for the braking radiation, no longer changes, and its value may be equated to the theoretical value, calculated for a beam with large finite cross-section (Figure 6a and b).

For materials with effective atomic number in the range 6-50 the relationship between the build-up factor and the maximal energy of the braking radiation is descirbed by a graph, which, beginning with about E_{max} = 20 Mev, tends to saturate /fig.8/.

The value of the build-up factor, for single thickness barriers in (g/cm^2) relation to the effective atomic number up to Z_{eff} 25-80 tends to increase, while for still greater effective atomic numbers tends to decrease.

An increase in the maximal energy of the braking radiation causes a displacement of the transition graph toward the side representing greater barrier thicknesses.

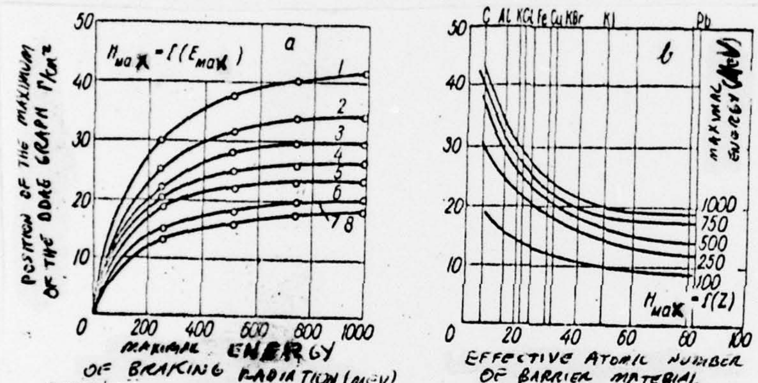

Fig.8. MAXIMA OF DDAE CURVES IN RELATION TO THE MAXIMAL ENERGY OF THE BRAKING RADIATION/a/, AND EFFECTIVE ATOMIC NUMBER OF THE ABSORBER /b/: CURVE 1 - GRAPHITE; 2 - ALUMINUM; 3 - POT. CHLORIDE ; 4 - IRON ; 5 - COPPER; 6 - POT. BROMIDE ; 7 - POT. IODIDE ; 8 - LEAD .

In the range $E_{max} < 100$ Mev an increase in the maximal energy of the braking radiation leads to an increase in the depth, at which the maximum of absobed radiation would occur, according to a linear law for the above process. Futher growth of the maximal energy leads to a decrease in the slope of the graph describing the relationship between the maximal energy and the position of the maximum of the DDAE.

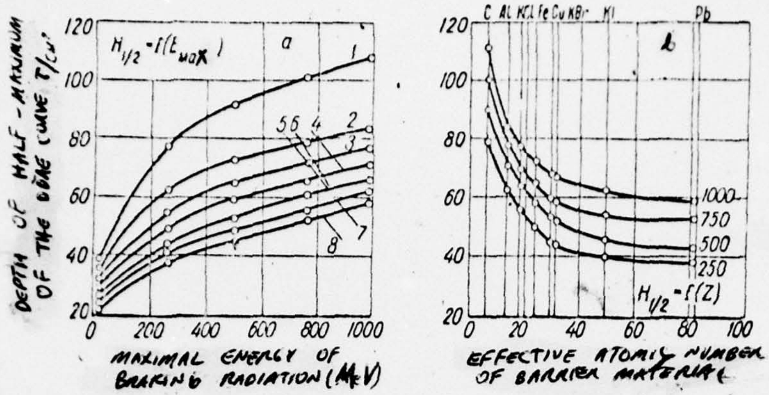

Fig. 4.

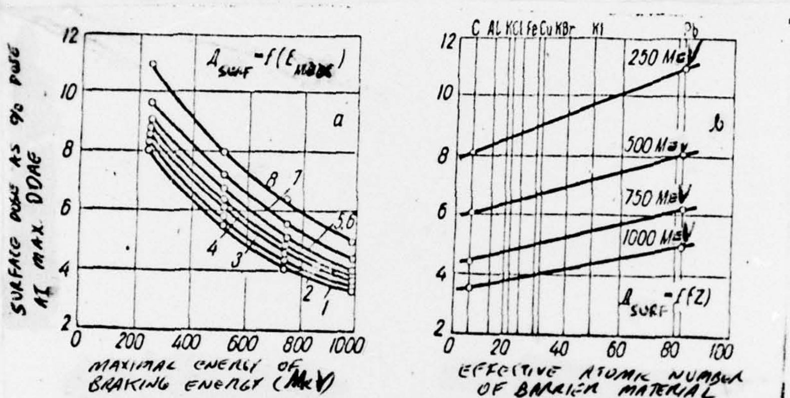

Fig. 5. VALUE OF SURFACE DOSE UNDER SAMPLE IRRADIATION BY BRAKING RADIATION IN RELATION TO THE MAXIMAL ENERGY OF THE BRAKING RADIATION /a/ AND EFFECTIVE ATOMIC NUMBER OF ABSORBER /b/.

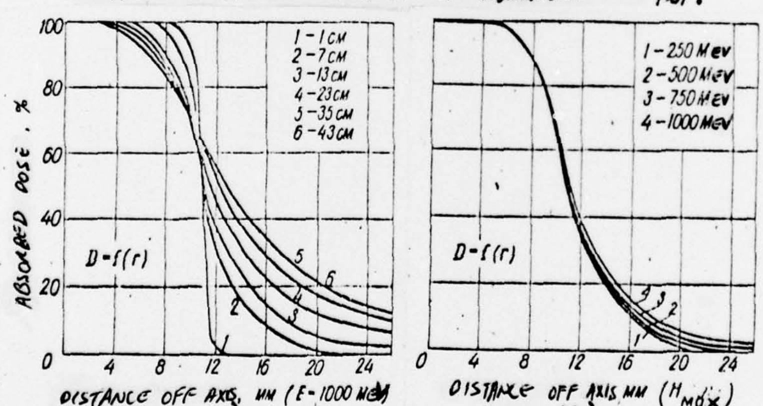

FIG 6 SPREAD OF ABSORBED RADIATION OUTSIDE BEAM LIMITS OF BRAKING RADIATION, WITH ITS PASSAGE THROUGH ALUMINUM /a/, AND ITS RELATION TO THE RADIATION ENERGY /b/.

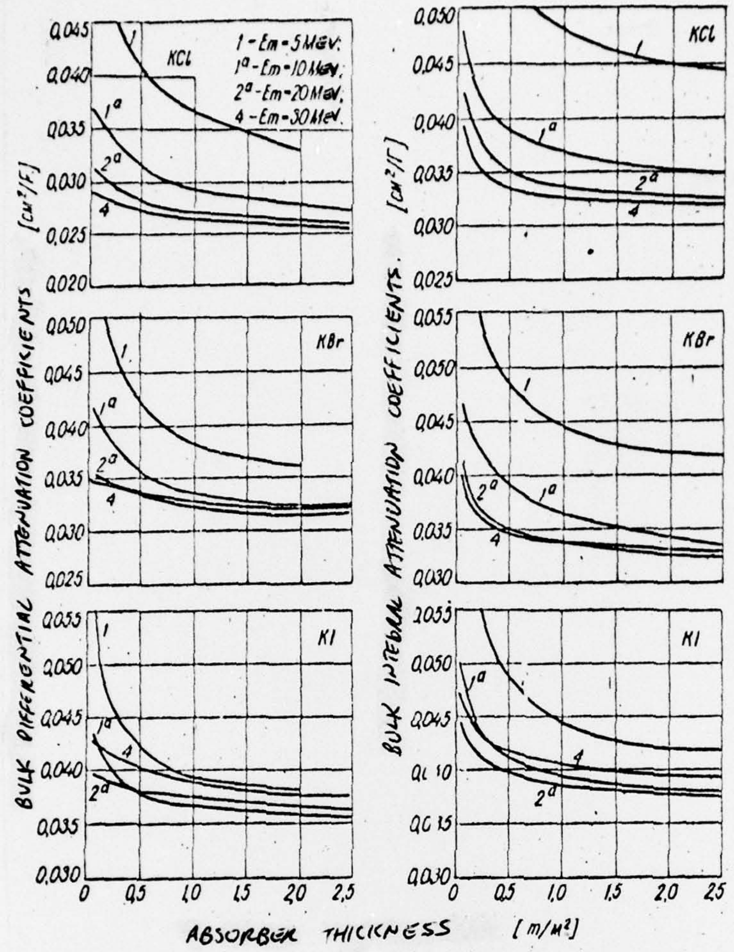

Fig.7. ATTENUATION COEFFICIENTS

An increase in the effective atomic number of the absorber material leads to a reduction in the thickness of the layer which separates the maximum ~~of~~ in depth of distribution absorbed energy the (DDAE) from the surface of the sample. in g/cm² (Figure 6a).

The degree to which the variation of the spectral composition of the flux of braking radiation, of the coefficients of attenuation, of the build-up factors, and of the distribution of the absorbed radiation obeyed the relationships which we have detailed, which connect

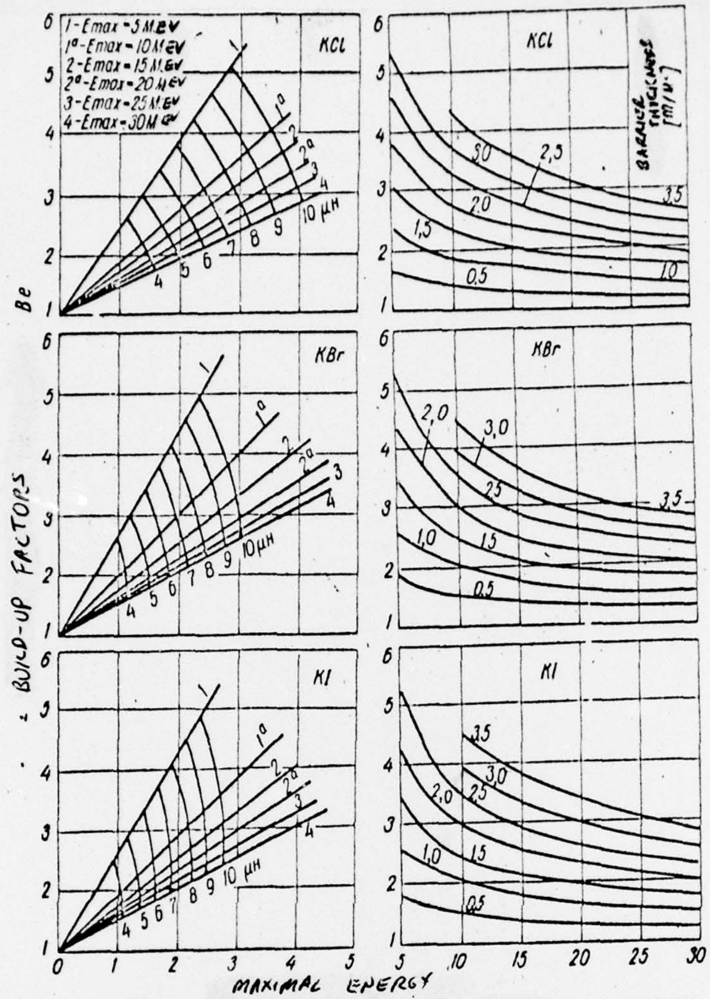

FIG. 8. BUILD-UP FACTORS OF BRAKING RADIATION IN ALKALI-HALIDE CRYSTALS

the above with the thickness and effective atomic number of the absorber, and the energetic and geometric parameters of the radiation flux, was measured by us for the range E_{max}=6-50 Mev. This data can be used in work in the fields of radiation physics, radio-physical technology, and also in other investigations of quantities or laws, related with the characteristics we studied.

In order to study the distribution of the flux of braking radiation beyond a barrier with an inhomogeneous structure, we developed an attractive mathematical model which allows us to study the transmitted radiation easily.

The flux distribution beyond a barrier, composed of heterogeneous granules, in which the particles within the aggregate have a close-to-petrographic composition, is determined from the density of the substance of the aggregate, as well as from the density of the matrix in which it is embedded, through the linear coefficients of attenuation, and the differential coefficients of linear inhomogeneity.

The nonuniformity of the secondary radiation flux, in comparison with the nonuniformity in the primary radiation flux, is small, and it is possible to disregard it if the size of the aggregate granules is significantly smaller than the thickness of the barrier.

By 'coefficient of linear inhomogeneity', which comes in in the description of the degree of barrier inhomogeneity, we mean the ratio of the sum of the chords between the bodies in the aggregate along the ray-path, with the entire path, followed by the ray in this direction. For structures with particles distributed by form or dimension this coefficient carries a statistical significance. The average value along all parallel paths (directions) through a given volume of the barrier represents the geometric density of the packing of the particles within the given volume of the matrix.

For random structures our mathematical model showed that, in the first approximation, the fluctuations in the coefficient of linear inhomogeneity are proportional to the density of the aggregate, and the standard deviation is inversely proportional to the thickness of the barrier. However, when a barrier diameter of some ens of particle-diameters is reached, further variation in the standard deviation is insignificant.

The correlation function of the linear inhomogeneity has, in the first approximation, a linearly-decreasing character in relation to the argument, equal approximately to the average radius of the prticles. In the previously mentioned acse the correlation function is zero. The amplitude of subsequent variation of this correlation function is insignificant. On the basis of these results a method was developed, involving the development of a pseudo-random number generator, for modelling the radiation field beyond a barrier with granular structure of known density (aggregate density), and with known fluctuations in the linear inhomogeneity given.

This method of mathematical modelling, for the electromagnetic fields of the braking radiation, gives us the required tools to conduct an investigation of the distribution of absorbed radiation in samples located inside various envelops, and beyond barrier of inhomogenous materials.

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