STRESS-INDUCED VARIATIONS IN THE SPECTRAL DISTRIBUTION OF γ-RADIATION FROM Cs^{137} TRANSMITTED BY GRAPHITED CARBON

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Investigation dealt with variations in the spectral energy distribution of gamma (Cs^{137}) radiation transmitted by graphitized carbon, in their dependence on vertical load, and was aimed at assembling experimental data for clarifying the observed variations in intensity of gamma radiation scattered on carbon, due to the presence of stress therein.

1. *Introduction*

Experimental results published hitherto (Bujok 1960; Bujok, Sujak 1962, 1964; Borecki, Bujok, Sujak 1962) revealed variations in the intensity of Cs^{137} gamma radiation transmitted by graphitized carbon according to the amount of vertical load applied to the latter. Investigation was effected with G.-M. as well as scintillation counters as radiation detectors. The counting frequencies obtained with these detectors were found to depend strongly on the vertical stress. Before practical application, these effects still require clarification. Accordingly, the decision was made to carry out futher measurements at the Central Institute of Mining, applying a different experimental setup and geometry of the measurements. It was our aim to obtain new data allowing to explain the intensity variations observed earlier for the case of graphitized carbon.

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2. *Method and measuring device*

Graphitized carbon used in the production of electrodes was applied, in the shape of blocks with an aperture bored in them wherein a radioactive (Cs^{137}) source of activity about 0.15 mC was placed.

Fig. 1 shows a diagram giving the dimensions of the blocks. The radioactive source was contained in a cylindrical plastic setting in the aperture in a manner to provide for its fixed position with respect to the block throughout the measurement. The specimen was placed in a hydraulic press acting on its surface of 17×20 cm^2 with variable force producing variable stresses in the graphitized carbon block under investigation; simultaneously, the radiation energetic spectrum emitted by the Cs^{137} preparation within the block was analyzed.

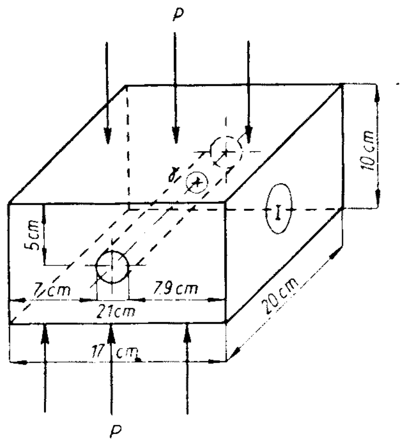

Fig. 1. Diagram of experimental carbon block

The detector was mounted at the site marked "*I*" in Fig. 1, at a point of the lateral face of the block. An *L. S.S.* counter was used (6097 *F* type photomultiplier made by *E.M.I.*, with Hilger NaJ(*Tl*) crystal of dimensions 1 3/4″ $\times$ 2″). The spectrometric probe as a whole was fed from a *P.Z.S.*-5 type stabilized source. The photomultiplier of the probe was supplied with a voltage of 820 V. The output pulses from the probe were fed to a cathode-follower and thence to the input of a proportional pulse amplifier of type *W.D.*-1. On amplification by about 50 dB the pulses of positive polarisation were transmitted through a concentric cable to a single-channel *A.A.*-1 type pluse analyzer. The output pulse from the analyzer was fed to a linear integrator of type *I.L.*010[1].

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[1] The *I.L.* 010 integrator had a linear meter scale. The measuring range (from 0 to 10^5 pulses per sec) was divided into five sub-ranges: to 10, 10^2, 10^3, 10^4 and 10^5 pulses per sec. The accuracy of registrations was better than $\pm 1\%$ of the values indicated in the upper half of the output meter scale and 1% of the full deviation in the lower half.

The integrator time-constant could be adjusted jumpwise from 0.025 sec to 50 sec according to the range of pulse frequency measured. The full range of frequencies corresponded to a voltage of 10 V on the integrator output.

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The integrator output voltage was recorded (with a linear compensator) over an appropriate voltage divider. The voltage range measured and recorded was up to 2.5 mV$\pm$10 μV.

In measuring we proceeded as follows: At a chosen value of the vertical load, the amplitudes of the transmitted radiation was analyzed with the probe at a fixed position ("I" in Fig. 1). On completing the measurements the load was increased and the amplitude distribution was measured repeatedly retaining the same position of the detector (position "I" in Fig.1).

Analysis of the spectrum started at the optimal position of the pressing planes, for which $p = 0$ kG/cm^2. Subsequent to determining the amplitude distribution in the gamma radiation at $P = 0$ kG, the load was increased jumpwise by about 500 kG up to 13000 kG.

The pressure on the block under investigation was raised by increasing that on the lower piston of the hydraulic press on which the block rested. As a result of insufficient adjustment of the upper sheeting (jaws) of the press, a shift in position of the piston amounting to about 2.5 mm occurred at a load of some 400 kG. At greater loads no further changes in position of the piston were found to occur. The shift by 2.5 mm at 400 kG entailed a displacement of the block upward, by the amount stated. Investigation of the time-constancy of the indications of the electronic device, as well as consideration of the effect on the results due to the changes in geometry as stemming from the above-mentioned shift proved the latter to be without influence on the amplitude distribution of the gamma radiation transmitted.

A yoke with holder for the scintillation counter was attached rigidly to the fixed casing of the upward-moving piston of the press. The design of the yoke was such as to allow for displacement of the detector parallel to the lateral surface, lengthwise and breadthwise (this had no effect on the results of the present investigation). The position of the detector with respect to the surface of the carbon block was determined to within 1 mm. The mechanical construction provided for constant geometry of the system throughout the measurements.

3. Results of the measurements

The scintillation counter allowed to analyze the amplitude distribution of the transmitted gamma radiation *versus* the amount of vertical load acting on the experimental graphitized carbon block. The device constructed by us admitted of investigating the intensity distribution along the surface in question *versus* the variable load (Bujok, Sujak 1964) and of following the variations of the spectrum on the surface (Bujok, in preparation).

For each value of the force applied to the block, we measured the energy distribution of the transmitted gamma radiation. The curves obtained at constant geometry and electric parameters of the system as a whole differed according to the value of the force. Variations were found to occur in the amplitude of radiation of 0.66 MeV energy as well as in the scattered radiation. The intensity varied accordingly.

Variations occurred in the recorded energy spectrum of the gamma radiation in the case of applied forces exceeding 3500 kG corresponding to pressures of about 10.3 kG/cm^2. Below this value no changes occurred in the shape of the spectrum, as exemplified by Fig. 2 for loads below 3500 kG, showing a segment of tape with the shape of the spectrum recorded.

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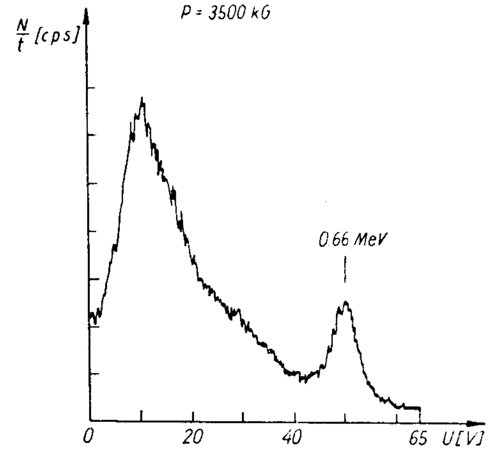

Fig. 2. Pulse amplitude distribution for gamma radiation transmitted by graphitized carbon, $P = 3500$ kG, $S = 340$ cm^2

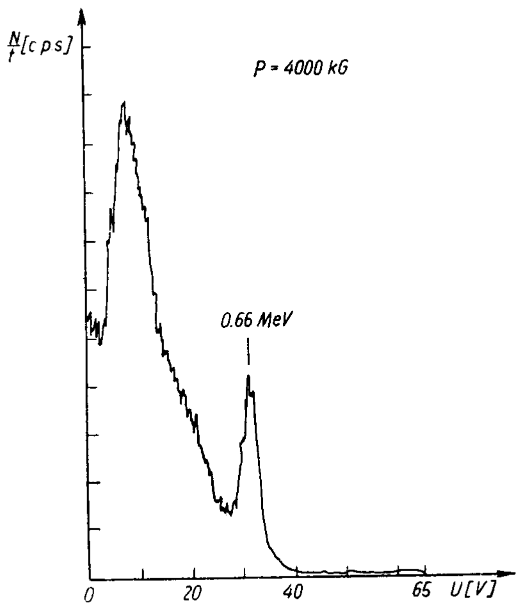

Fig. 3. Pulse amplitude distribution for gamma radiation transmitted by graphitized carbon, $P = 4000$ kG, from a first measurement at steady state of the force applied

Variations first appear in the amplitude spectrum for $P = 4000$ kG (about 11.8 kG/cm^2), as shown in Fig. 3. The radiation peak of energy 0.66 MeV shifts from an amplitude of about 50 V to about 30 V. The peak of back-scattered radiation, too, is shifted, albeit by a lesser amount. A second measurement at steady-state value of the applied forces ($P = 4000$ kG) yielded the spectrum of Fig. 4. The distribution measured behaves as in the initial phase if growing pressure (up to 3500 kG) in the interval of large amplitudes. An amplitude of about 50 V corresponds to 0.66 MeV energy. At an amplitude of some 41 V this

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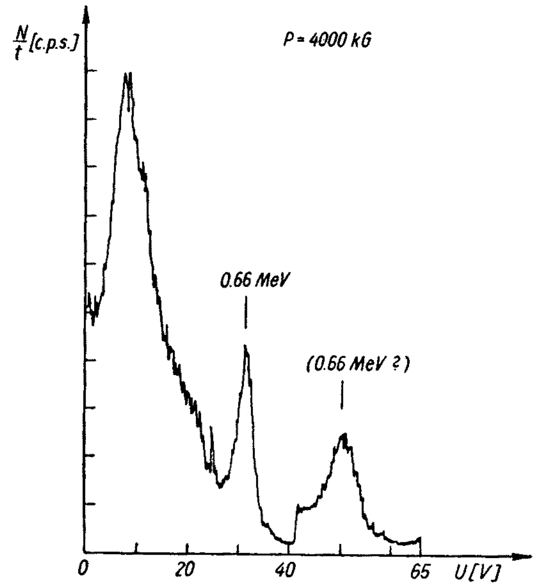

Fig. 4. Pulse amplitude distribution for gamma radiation transmitted by graphitized carbon, $P = 4000$ kG, from a second measurement on attaining steady state of the force applied

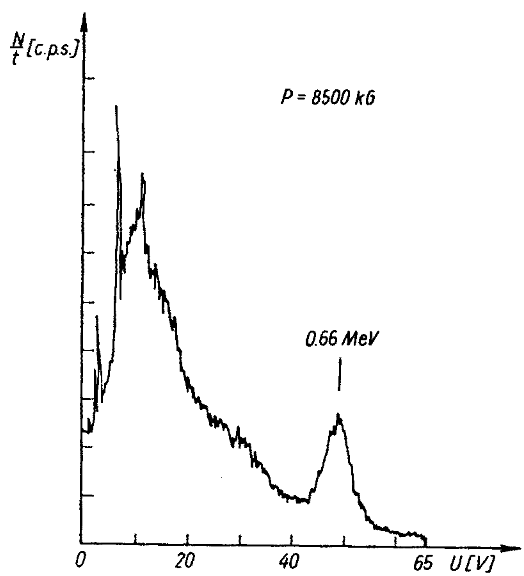

Fig. 5. Pulse amplitude distril ution for gamma radiation transmitted by graphitized carbon $P = 8500$ kG

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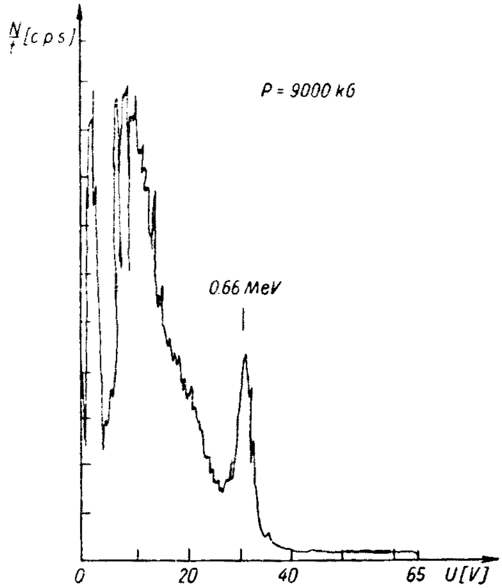

Fig. 6. Pulse amplitude distribution for gamma radiation transmitted by graphitized carbon, $P = 9000$ kG

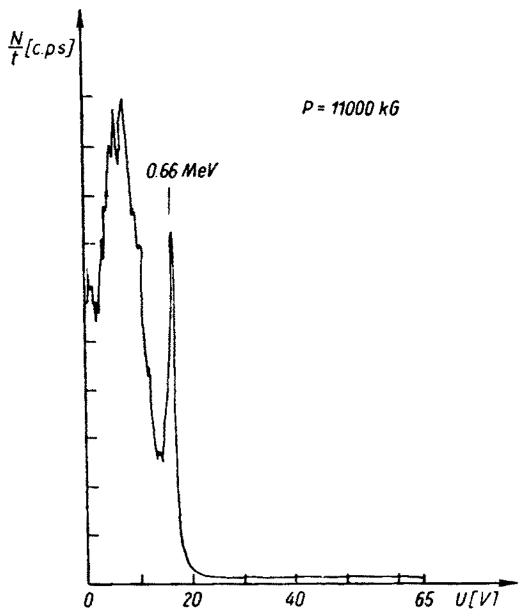

Fig. 7. Pulse amplitude distribution for gamma radiation transmitted by graphitized carbon, $P = 11000$ kG

shape becomes perturbed, and there appears a jump in recorded amplitude. At smaller amplitudes the shape is that of Fig. 3 *i.e.* an amplitude of about 30 V now corresponds to 0.66 MeV. At a load of 5000 kG, the spectral distribution reverts to the shape measured previous to loading.

As the load is increased above 5000 kG no well-defined changes appear in the amplitude distribution recorded. It is only at 8500 kG (about 25 kG/cm^2) that the recorded intensity in the amplitude interval between 0 and 10 V undergoes a change (Fig. 5). The peak corresponding to 0.66 MeV radiation energy is now related throughout to an amplitude of about 50 V. An increase in load to 9000 kG entails an increase in intensity in the low energy range (Fig. 6), whereas radiation of energy 0.66 MeV is now no longer related to an amplitude of 50 V but to one of about 30 V, as previously. As the load is increased still further, the peak (0.66 MeV) remains at a constant value of about 30 V.

This shape of the spectrum is maintained up to forces below 11000 kG. However, at this latter value (corresponding to about 32 kG/cm^2), a further displacement in amplitude of the radiation recorded appears. An amplitude of no more than approximately 16 V now corresponds to radiation of 0.66 MeV (Fig. 7). At a pressing force of 1200 kG the amplitude

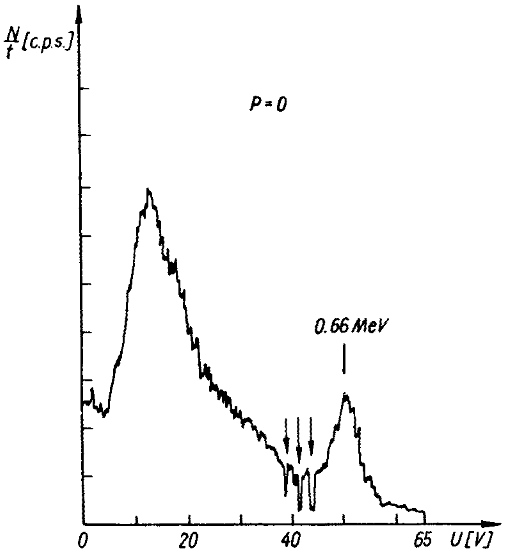

Fig. 8. Pulse amplitude distribution for gamma radiation transmitted by graphitized carbon, from a first measurement on de-stressing of the material *i.e.* at $P = 0$ kG

returns to its previous value of about 30 V and maintains itself at this value to the end of the experiment *i.e.* up to 13000 kG.

Subsequent to loading with 13000 kG the material was de-stressed *i.e.* a force of 0 kG was applied. The shape of the spectrum as obtained for the de-stressed block is shown in Fig. 8. For an amplitude of about 40 V, the normal shape of the spectrum has undergone a perturbation. Three minima (see arrows) of the intensities appear. A second measurement yielded a spectrum that was already normal, as shown *e.g.* in Fig. 2.

In all, 26 measurements of the amplitude distribution of the transmitted gamma radiation were made for loads ranging from 0 to 13000 kG corresponding to pressures of 0 to about 38 kG/cm². For a more comprehensive representation of the changes occurring in the spectrum, we assembled in Fig. 9 the variations in amplitude for the energy peak of 0.66 MeV

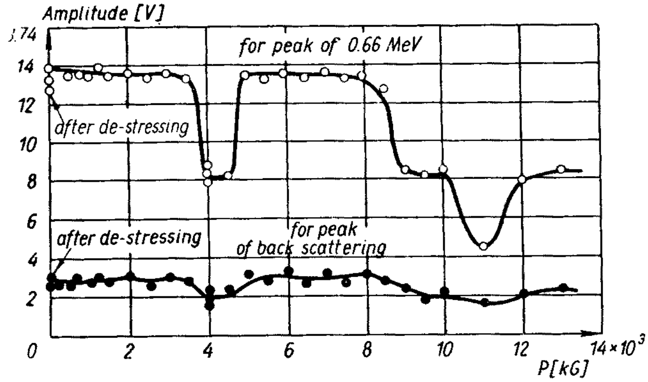

Fig. 9. Shape of changes in amplitude A for radiation of 0.66 MeV energy and for back-scattered radiation, *versus* the force applied P

and backward-scattered radiation, as *versus* the force applied. Two minima are found to occur for the same force. The changes in amplitude for the backward-scattered radiation are seen to be smaller than for 0.66 MeV.

Simultaneously with the changes in amplitudes, changes occur too in the intensity of the entire spectrum comprising both the back-scattered radiation and that of energy 0.66 MeV. These changes are show in Fig. 10 as a function of the force applied. At values

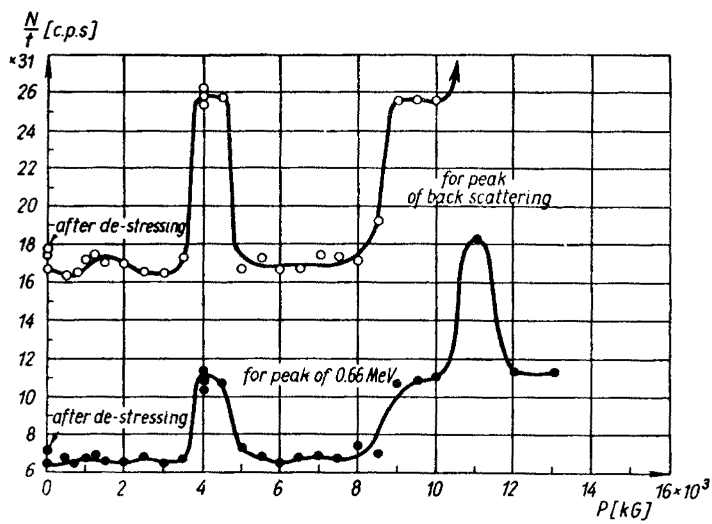

Fig. 10. Shape of the recorded changes in intensity $\frac{N}{t}$ of 0.66 MeV energy and back-scattered radiation, *versus* the value of the force applied P

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of the force corresponding to a minimum of the amplitude variation curve, that of the intensity variations (couting rate) reveals maxima. The intensity and changes in intensity for the back-scattered radiation are larger than for the 0.66 MeV energy peak. At forces above 10000 kG such variations altogether exceeded the range of our recording device. For the curve $N/t = f/(P)$ (radiation intensity *versus* the load, Fig. 10) and the curve $A = f(P)$ (amplitude *versus* the load, Fig. 9) exhibits extrema for loads of about 4000 and 11000 kG. In relation with the observed changes in the spectrum of the radiation analyzed, the distance changes between the peak corresponding to an energy of 0.66 MeV and that of the back-scattered radiation. These changes are shown in Fig. 11 as a function of the vertical load,

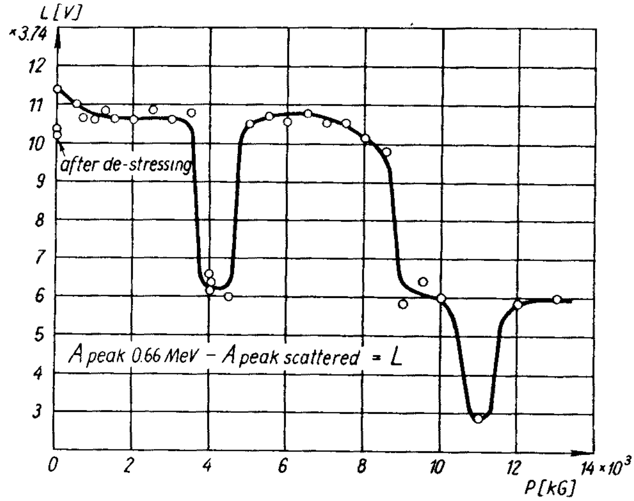

Fig. 11. Differences in amplitude L (from the above distributions) between radiation of 0.66 MeV and back-scattered radiation, *versus* the force applied P

in units of the pulse amplitude $L = f(P)$. The distribution curves obtained show that, at forces of about 4000 kG and between 8000 and 13000 kG corresponding to the smallest distance L (Fig. 11) and smallest amplitude A (Fig. 9), a change in intensity of the radiation N/t occurs in the range from zero energy to that corresponding to back-scattered radiation (Figs. 5 and 6).

4. Conclusion

The above results prove that interaction between gamma (Cs^{137}) quanta and the graphitized carbon specimen depends on the state of stress in the later. Previously observed (Bujok, Sujak 1962, 1964) variations in intensity of the radiations can probably be attributed to changes in the energy distribution of the radiation transmitted as due to load on the specimen. Earlier results (Bujok, Rogów 1960; Borecki, Bujok, Sujak 1962) on changes in intensity of gamma radiation scattered on bulk carbon would now no longer seem to be entirely inaccessible to explanation. Investigation now proceeding at the Central Institute of Mining may well contribute towards an explanation of these differences in the interaction of gamma radiation and carbon subjected to the effect of external forces.

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