ON THE PRODUCTION OF RADIOACTIVITY IN ROCKS BY COSMIC RAYS*+

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INTRODUCTION

Cosmic rays should induce radioactivity in the rocks near the surface of the ground by three processes:

1) The capture of cosmic ray neutrons.

2) The capture of negative μ-mesons in medium or heavy elements.

3) The spallation of all the elements by the nucleonic components and the π-meson component of the cosmic radiation.

The radioactivity produced by process (1) will be diluted by

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the capturing nuclide and it will not be possible to concentrate it except by separation of isotopes and hence it is too difficult to detect.

The radioactivity produced by processes (2) and (3) can yield radioisotopes of different elements from the irradiated nucleus. It is then possible to make a great concentration by chemical means, and it might be possible to detect and measure them.

We have made an attempt to detect the 2.5×10^6 yr Be^{10} in limestone ($CaCO_3$). We did not detect it, because probably the radioactivity in the largest amount of material we could process was smaller than the smallest radioactivity we could detect.

We can estimate the amount of Be^{10} expected in the $CaCO_3$. The mean production rate of Be^{10} in the atmosphere has been estimated by Peters[1] (1940) to be between 3 to 6 atom/cm^2-min and by Arnold[2] (1954) as 2.4 atom/cm^2-min. We will take 3.3 atom/cm^2-min for our calculation. This can be expressed also as 3.3×10^{-3} atom/g-min of air. We will assume that the production of Be^{10} in the atmosphere will follow the curve of star production given by Puppi and Dallaporta[3] (1952). From this curve we obtain that the ratio of the production rate at sea level to the mean production rate is 3×10^{-3}. We will assume that the production of Be^{10} per gram of C and O in $CaCO_3$ is the same as the production per gram of air. This will give us 6×10^{-6} dpm/g as the specific activity of Be^{10} in equilibrium in the limestone.

It is assumed in this calculation that the rock has stood near the surface for a period longer that the half-life of Be^{10}, and that the cosmic radiation has been constant during that period.

It is very unlikely that a rock will stay near the surface of the ground for such a long time, and the activity calculated is only an upper limit. The actual activity could be perhaps one order of magnitude smaller in the best of cases.

EXPERIMENTAL METHOD

Some 30 Kg of limestone were dissolved in HCl, 20 mg of Be carrier added, and the solution was diluted to 500 liters. The hydroxides of impurities in the limestone were precipitated with NH_4OH, the supernatant rejected and the hydroxides washed twice with 500 liters of water. The hydroxides were dissolved in HCl, enough Versene was added to complex the bulk of the cations, and beryllium hydroxide precipitated with NH_4OH; the Versene treatment then was repeated. Since the Be was still very impure, it was dissolved in HCl, taken to dryness, and dehydrated to separate the silica. The filtrate was evaporated to dryness and made 1 M in HNO_3, the P was separated by the phospho-molibdate method, and the hydroxides precipitated, filtered, and dissolved in HCl. The Be was now purified by extraction with pentanedione and benzene as described by Arnold. The two samples shown in table I were from 20 and 35 kg of limestone respectively, and their chemical yields were 18 % and 37 % .

The samples were counted with an end-window Geiger counter having an efficiency of 10% and a background of 2.5 cpm. The results are shown in table I. We treated other samples of limestone, but they had enough Be to make them useless on account of self-

absorption.

In the first column of the table is shown the origin of the sample; in the second column is shown the activity found with the actual error, this error being due to variations of background from one day to another; the third column was calculated assuming that an activity as large as the error could have been detected, and making corrections for chemical yield, geometry, back-scattering, and absorptions; the calculated activity for Bolivia shown in the fourth column is higher due to the altitude.

From this table, one can draw the conclusion that one needs to process samples about one hundred times bigger and free from Be; or to have a detector one hundred times more sensitive, to settle the question of the radioactivity produced in rocks by cosmic rays.

Table I

Sample	Observed activity (cpm)	Upper limit of observed specific activity (10^{-6} dpm/g)	Calculated upper limit of specific activity (10^{-6} dpm/g)
Brazil	0.01 ± 0.08	220	6
Bolivia	-0.04 ± 0.10	80	60

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2. Arnold, J. R., Science 124, 584 (1956)

3. Puppi, G. and Dallaporta, N. , Progress in Cosmic Ray Physics, edited by J. G. Wilson (North-Holland Publishing Company, Amsterdam), p. 378 (1952)