RADIOACTIVE BERYLLIUM IN THE ATMOSPHERE AND ON THE EARTH

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Abstract

It is estimated that about 1,000 nuclei of radioactive Be^{10} (2·7 million years half-life) are produced per square meter per second by cosmic ray induced nuclear disintegrations in the atmosphere. The conditions for observing the resulting activity in rain water and in various regions on the earth are favourable and may be useful for measuring sedimentation rates and other geological surface changes during the Tertiary.

Long-lived radioactive isotopes are continuously being created in the upper atmosphere as a result of nuclear disintegrations caused by cosmic ray particles. Carbon 14[1] and recently Tritium,[2] have been shown to arise in this manner. Since the atmosphere contains also large amounts of stable carbon nuclei in the form of CO_2 and stable hydrogen nuclei in the form of water vapour, these cosmic ray produced radio isotopes are always highly diluted; the samples collected on the earth have, therefore, a correspondingly low specific activity.

There is one other long-lived radio isotope which can be produced by disintegration of nitrogen and oxygen nuclei, the beryllium isotope $Be.^{10}$ Because of its long half-life (2·7 million years),[3] this isotope may be useful for establishing chronology of geological events in the Tertiary. On first consideration one might think that the expected radioactivity is too weak to measure with existing techniques, not only because the production of Be^{10} is probably still smaller than the already small production of tritium; but primarily because the very much longer half-life makes detection of small quantities more difficult. However, these disadvantages may easily be offset by the fact that Be^{10} in the atmosphere is not contaminated by any stable beryllium nuclei.

Presumably Be^{10} will be oxidized fairly rapidly after creation, and will reach the earth dissolved in rain water; these assumptions suggest themselves from analogy with the behaviour of cosmic ray produced tritium.

Though proof is still lacking, I shall assume for the present that the Be^{10} nuclei will reach the earth in a time short compared to their half-life. The dilution of Be^{10} with the stable isotope Be^{9} will be small even after the nuclei have reached the earth's surface, because beryllium is a rare element in the lithosphere, hydrosphere and biosphere. The average beryllium content of igneous and sedimentary rocks has been estimated as two parts per million[4] and the beryllium content of sea water seems to be so small as to have escaped detection.[4, 5] Therefore, it should be possible to obtain on earth, by chemical separation, samples of Be^{10} with a high specific activity.

It has recently been demonstrated[6] that a freshly poured nuclear emulsion is an extremely sensitive β-ray counter for samples of high specific activity; it is capable of measuring, against ordinary background, disintegration rates of the order of 1 dis./hour, provided that the activity can be concentrated in a volume 10^{-5} c.c. or less. This type of detector would be suitable for Be^{10} which emits electrons with an upper energy limit of 550 KeV. It is this refinement in detection technique which makes it hopeful to attempt the separation of Be.[10] It would be sufficient to have 10^{11} nuclei in solution, and a concentration corresponding to about one part of Be^{10} in 10 million. Such a sample corresponds to the specific activity of 5,000 dis./min., cm.^{3} of solution. With conventional electronic counting techniques the radioactive sample would have to be about 1,000 times as large, but its specific activity could be much lower.

The production rate of Be^{10} can be estimated fairly reliably by the following considerations:—

(*a*) The rate of nuclear disintegrations of nitrogen and oxygen in the atmosphere (star production) at the equator is 0·75 per second in a column extending the full height of the atmosphere and having a cross-section of 1 cm.^{2} It increases with latitude and reaches 3·3 per second at latitudes higher than 60°.*

(*b*) The spalliation reactions in light elements observed in cosmic radiation and in experiments with high energy particle accelerators, permit a reasonably safe estimate of the distribution frequency of various disintegration products. It seems that in most cases the collision between a fast nucleon and a nitrogen or oxygen

* These numbers have been calculated using the known intensity of primary radiation at various latitudes, the existing information on collision cross-sections of energetic protons and neutrons in air and the measured altitude variation of star production in nuclear emulsions.

nucleus does not lead to complete disintegration of the latter into singly or doubly charged particles; in the majority of cases larger aggregates of the nuclear matter belonging to the target nucleus will survive. All stable and long-lived nuclides are represented among these residues[7] and a conservative estimate leads to the prediction that 5% of all collisions should result in the production of Be^{10}.

We may expect on earth a decay rate of Be^{10} equal to its rate of production and, therefore, an average radioactivity of 3 to 6 disintegrations per minute per cm.^{2} of surface area. The total equilibrium accumulation of Be^{10} on earth will then amount to about 1,000 tons.†

It may be possible to detect the Be^{10} soon after it reaches the earth. If we take 90 cm. as the mean annual precipitation,[4] we expect rain water to contain on the average not less than 16,000 Be^{10} nuclei per c.c. One can apparently extract an adequate sample from rain water by means of an ion-exchange column; we have lately extracted Be^7 from water with a comparable beryllium concentration (30,000 atoms per c.c., in the form of radioactive $Be\,Cl_2$) without any particular difficulty.

Ultimately, however, tracing Be^{10} in the oceans and on land presents the more interesting problem, because one may hope to use it for measuring rates of sedimentation in the oceans and on continents, rates of weathering of rocks and various other types of geological surface changes which have occurred during the past few million years. Although it seems impossible at this stage to predict the life-history of the Be^{10} nuclei after they have reached the earth, it is nevertheless possible to present arguments in favour of their being detectable. The nuclei which reach the sea in the form of rain could either:—

(*a*) Form a soluble or insoluble compound and stay in solution or suspension in the sea water.

(*b*) Sink to the ocean bottom.

(*c*) Get adsorbed in the sedimentary deposits on the continental shelves.

(*d*) Become concentrated in organic matter.

† Here I make the assumption that the intensity of cosmic radiation has not changed appreciably for several half-lives. Its constancy has been proven so far only for the past ~ 30,000 years[8]) but the interpretation of recent measurements on the He^3/He^4 ratio in meteorites[9] make it likely that cosmic radiation of approximately equal intensity has been in existence for times of the order of at least several 100 million years.

Whatever their fate, the presence of Be^{10} in the oceans should be observable and measurable.

The least favourable case from the point of view of concentration is the uniform distribution of Be^{10} throughout the volume of the sea. The estimated equilibrium accumulation of 4×10^{12} atoms/cm.^{2} together with an assumed mean ocean depth of 3,800 meters[4] leads to a concentration in sea water of 10^7 atoms/c.c. and therefore (neglecting losses) 10 litres of sea water represent a sample of adequate size. Here the extraction and purification will be somewhat more difficult than in the case of rain water, but by adding Be^7 as tracer (half-life 53 days) a satisfactory chemical procedure can probably be worked out.

If the Be^{10} should form deposits on the ocean floor where sedimentation rates of the order of 1 cm. in 20,000 years have been measured[10] only 5 c.c. of deposit are needed for a sample of adequate strength.

If Be^{10} instead of sinking to the bottom were adsorbed in the sediments of the continental shelves, the samples would have to be larger because of the higher sedimentation rates, but they would probably not have to exceed 500 gm. since the effect of high sedimentation rates is partly compensated by the concentration of Be^{10} from the large ocean area into the smaller area covered by the shelves. Similar quantities of sample would be required for extracting Be^{10} on land from sedimentary rocks formed in the process of weathering of igneous rocks in regions where the surface layers are removed at the rate of about 1 g./cm.^{2} per 200 years. The recovery of Be^{10} from sedimentary rocks presents, however, some additional difficulty; here we may expect a sample of the required size to be diluted with approximately 1 mg. of stable beryllium. Thus, even if the beryllium has been well purified chemically, the specific activity of the resulting sample will be somewhat lower than what seems at present required for detection by the nuclear emulsion technique.

If Be^{10} activity were found on the land surface, it is possible that its cosmic ray origin will manifest itself by a very appreciable latitude effect; in the oceans on the other hand this effect may have become obscured or entirely obliterated by mixing due to ocean currents. The latitude effect if observable should permit conclusions about the constancy or fluctuations in energy distribution of the primary cosmic radiation during the past several million years.

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