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^{261}Rf; NEW ISOTOPE OF ELEMENT 104*

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March 1970

Abstract

We have discovered a 65-second, alpha-particle-emitting isotope of element 104, rutherfordium[1)], by bombarding ^{248}Cm with ^{18}O ions. The identification of the isotope as ^{261}Rf is based on milking the 26-second daughter, ^{257}No.

In an earlier paper[2)] we have reported the discovery of two alpha-particle-emitting isotopes of element 104, ^{257}Rf and ^{259}Rf. In our subsequent studies of rutherfordium we have found yet another alpha-particle emitter that we assign to ^{261}Rf.

A 50-μg ^{248}Cm target was electrodeposited from an isopropyl alcohol solution in an area of 0.18 cm^2 on a substrate sandwich consisting of 0.1 mg/cm^2 Pd sputtered onto 2.2 mg/cm^2 Be. The isotopic composition of the target was 2.0% ^{244}Cm, 0.06% ^{245}Cm, 3.4% ^{246}Cm, 0.01% ^{247}Cm, and 94.5% ^{248}Cm. The new alpha-particle activity was produced by bombarding the target with ^{18}O ions accelerated by the Berkeley heavy ion linear accelerator (Hilac). The energy of the 10.4 MeV/nucleon particles from the Hilac was adjusted by a stack of Be metal-foil degraders and measured by a solid-state detector looking at an angle of 30° at the particles scattered from the target.

The apparatus used was similar to that described in Refs. 2, 3 and 4. The transmuted atoms recoiling from the target were swept by helium gas from

the target region through a 0.3-mm-diam orifice into vacuum, where the helium jet escaping from the orifice deposited them onto the periphery of a 45-cm-diam wheel. By periodically rotating the wheel these atoms were placed into positions adjacent to five Si-Au surface-barrier detectors. To make possible a physical separation and an efficient detection of two genetically-related alpha activities, two movable and two stationary detectors were arranged in each detector station as shown in Fig. 1. When the atoms on the wheel, the so-called mother atoms, decay by alpha emission, they have an equal probability of either emitting an alpha particle or an alpha-recoil atom into the detector facing the wheel. The alpha particles will be recorded by the detector as mother events, and the subsequent decay of the recoil atoms imbedded in the detector will be registered as daughter events. When the detector facing the wheel is periodically moved off-wheel to a position facing a stationary detector, only the decay of the atoms which are recoiled into the detector, i.e., daughter atoms, is seen in a nearly 4π geometry. The possibility of any atoms getting on the detectors directly without a recoil impulse of its precursor is less than 10^{-5} as shown by a study of ^{214}Ra atoms. There were five stations like the one in Fig. 1 equally spaced along the rim of the vertical wheel. Each wheel cycle and shuttle period was divided into four time subgroups of equal length. Besides the pulse height, each observed event was "tagged" with a detector identification signal as well as signals relating it to the prevailing shuttle condition and pertinent time subgroups. This information was stored via a PDP-9 computer on IBM tape and later sorted off-line to give 160 x 512 channel alpha spectra.

The bombardments of the ^{248}Cm target with ^{18}O ions of 90-100 MeV energy resulted in the alpha particle spectra displayed in Fig. 2, which shows combined spectra recorded by the movable detectors when facing the wheel. Each

of the spectra represents one of the five detector stations and the sum of the five is plotted topmost. The wheel-cycle rate was 48 seconds. Because of a few nanograms of lead and mercury impurities in the target, a host of alpha peaks due to decay of Po, At, Rn, Fr, Ra, Ac, and Th isotopes are present. A spectrum resulting from bombardment of a natural lead target is shown in Fig. 3. By comparison of Fig. 2 with Fig. 3, it is clear that only the complex of peaks at 8.2-8.3 MeV region is due to ^{248}Cm in the target, the rest of the peaks beyond an energy of about 7.5 MeV having been induced by the lead impurity in the target. We believe that the complex of peaks at 8.2-8.3 MeV is a mixture of alpha peaks present in the decay of ^{261}Rf and its 26-sec daughter, ^{257}No. The alpha-particle spectrum of the latter is composed of 8.22 (55%), 8.27 (26%), and 8.32 MeV (19%) peaks[5], and superimposed on this cluster of peaks and virtually indistinguishable from it are the alpha groups due to ^{261}Rf. The main alpha-particle group of ^{261}Rf seems to be at 8.28 ± 0.02 MeV. The half-life of the joint mother-daughter activity is 70 ± 10 seconds.

In Fig. 4 the distribution of daughter events recorded by the crystals in the off-wheel position is displayed in two ways. To the right, the number of daughter events observed in each time subgroup at each of the five detector stations is shown. The number of counts detected at each detector position is determined by the half-life of the ^{261}Rf mother atoms and from these numbers we obtain a half-life value of 70 ± 15 seconds. On the left hand side of Fig. 4 the same daughter counts have been combined according to the time interval in which they were observed after each daughter-measuring sequence was started by the shuttle movement. An analysis of this distribution gives a daughter half-life of 25 ± 10 seconds consistent with the half-life of 26 sec of ^{257}No[5]. The ratio of events between 8.15 MeV and 8.35 MeV recorded by the detectors in the

on-wheel position to those recorded by the detectors in the off-wheel position was 500:73 ≈ 6.8, which agrees within statistical uncertainty and the accuracy of geometry factors with the value 6.0 obtained by simulating the measurement in a computer. The computer analysis also shows that the decay of the mother-daughter complex takes place with a "half-life" that is about 7% longer than that of the mother activity alone. Correcting for this effect, we obtain a half-life of 65 ± 10 seconds for the mother activity. Practically no ^{257}No atoms are produced directly by the α5n-reaction at the bombarding energies used. Altogether, as indicated above, the experimental data are consistent with the interpretation of the 8.3-MeV, 65-sec alpha activity being the alpha precursor of ^{257}No and thus unambiguously identifying it as ^{261}Rf.

The excitation function for the reaction, ^{248}Cm(^{18}O,5n)^{261}Rf, was measured only crudely because of the low cross section and the emphasis placed on the study of the genetic relationship. The yield of ^{261}Rf from experiments resulting in the spectra of Fig. 2 corresponds to a cross section of approximately 5.10^{-33} cm^2. The bombarding energies were close to the calculated peak (97 MeV) of the excitation function[6].

The ^{248}Cm target was also bombarded with ^{13}C and ^{16}O ions. In the former case ^{257}No was produced in relatively large amounts, and a value of 26 ± 2 seconds was obtained for its half-life[5]. In the latter experiments ^{257}No was present from ^{248}Cm(^{16}O,α3n)^{257}No[7]. It again decayed with the proper half-life. The fact that there was no sign of the presence of ^{261}Rf indicates that the ^{248}Cm(^{16}O,3n)^{261}Rf cross section is of the order of a nanobarn or less, which agrees with predictions[6].

Our search for spontaneous-fission branching in the decay of ^{261}Rf has not produced positive results. The upper limit for such a branching is about 10% based on measurements carried out simultaneously with the alpha-decay studies.

Taking advantage of the relatively long half-life of ^{261}Rf, we have recently used it in experiments designed to establish the chemical properties of element 104[8].

We gratefully acknowledge the invaluable assistance of the personnel at the Hilac in making these experiments possible. One of us (P.E.) is indebted to the National Research Council for Sciences, Helsinki, Finland, for financial support.

FOOTNOTES AND REFERENCES

*This work was done under the auspices of the U. S. Atomic Energy Commission.

†On leave of absence from Department of Physics, University of Helsinki, Finland.

‡Guest Scientist supported by the National Research Council for Sciences.

1. For reasons detailed in Ref. 7, we have proposed that the element 104 be named rutherfordium. This name and the corresponding symbol Rf is used throughout this article.
2. A. Ghiorso, M. Nurmia, J. Harris, K. Eskola and P. Eskola, Phys. Rev. Letters 22, 1317 (1969).
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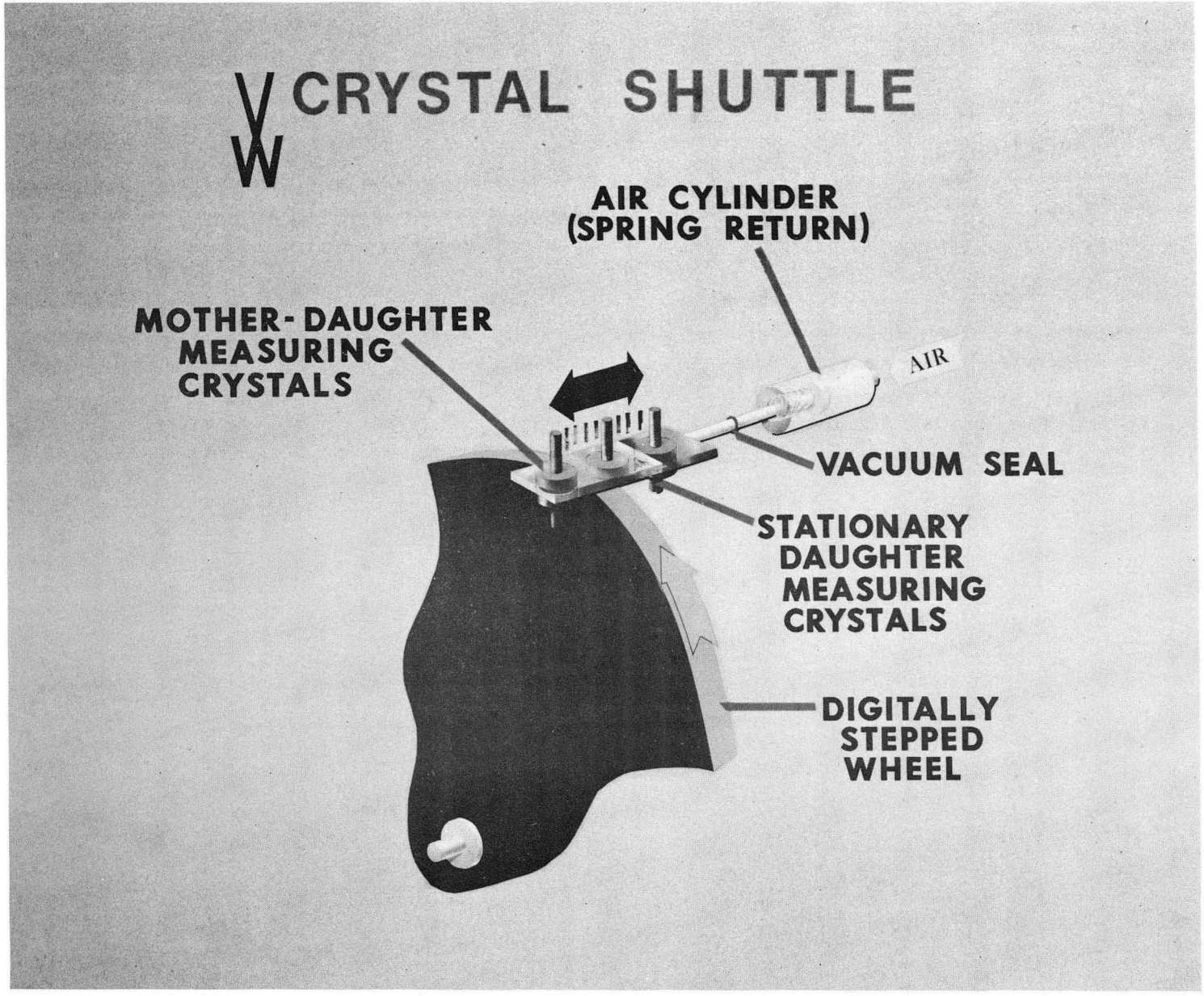
6. T. Sikkeland and D. F. Lebeck, unpublished work.
7. A. Ghiorso, The Robert A. Welch Foundation Conferences on Chemical Research, XIII. The Transuranium Elements-The Mendeleev Centennial, Nov. 1969 (to be published).
8. R. Silva, J. Harris, M. Nurmia, K. Eskola and A. Ghiorso, to be published.

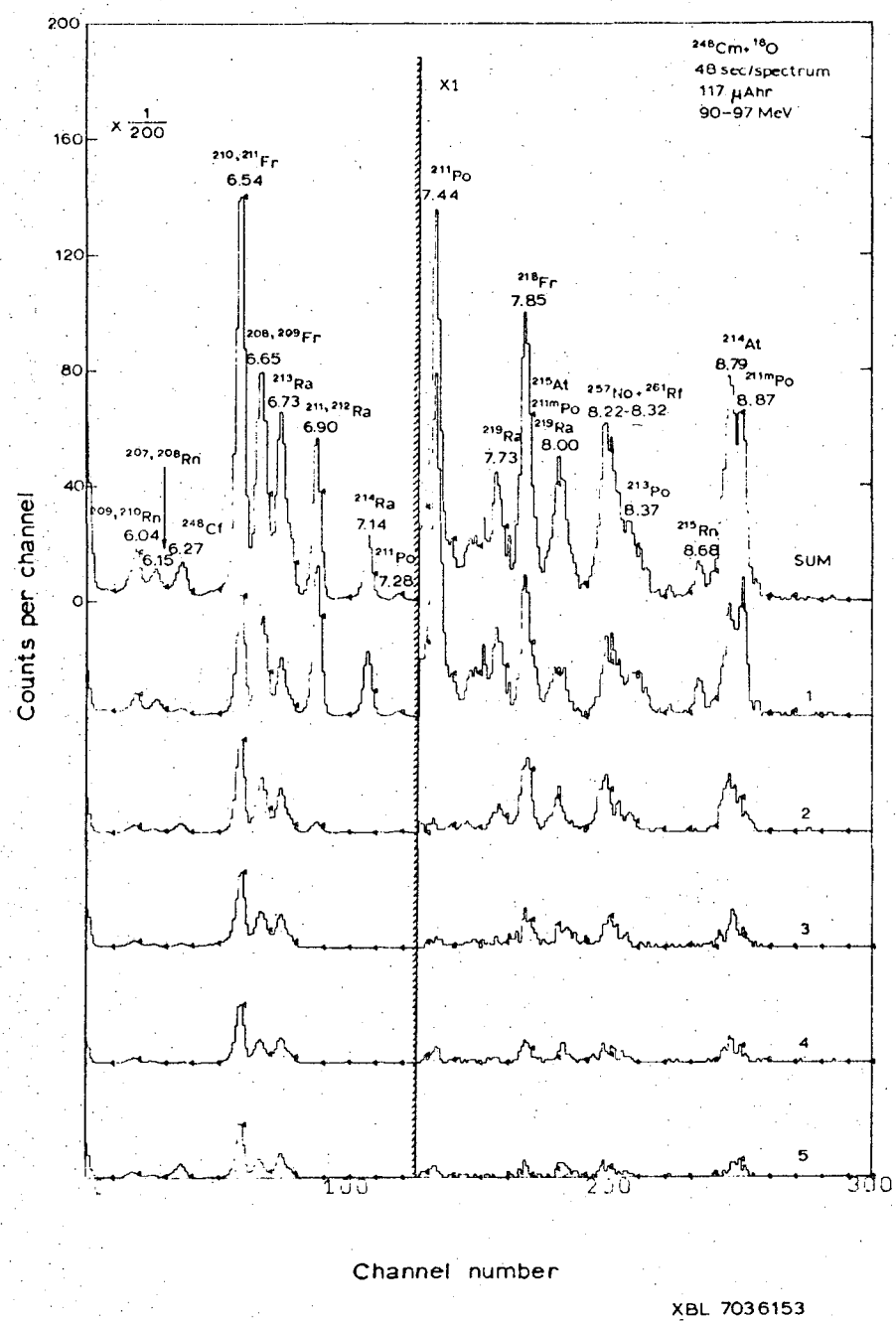
FIGURE CAPTIONS

1. Detector-shuttle system for alpha-recoil milking experiments. Schematic representation of the daughter-milking method used with the five detector-station apparatus. At each station there are four detectors.
2. A series of alpha spectra of the activities produced by bombardment of ^{248}Cm target with ^{18}O ions. Minute lead and mercury impurities in the target give rise to most of the alpha peaks in the spectra. The $^{218}Fr \longrightarrow {}^{214}At$ chain is presumably kept alive by a one-minute alpha-emitting isomer of ^{222}Ac.
3. An alpha spectrum resulting from bombardment of lead with ^{18}O ions. The spectrum is for comparison with the sum spectrum in Fig. 2, although it was measured with a four detector-station system and at a wheel-cycle rate of 60 seconds.
4. The distribution of alpha-decay events of 8.2-8.4 MeV recorded by the detectors in off-wheel position. The histogram marked by crystal number above each column shows the total of daughter counts recorded at each detector station.



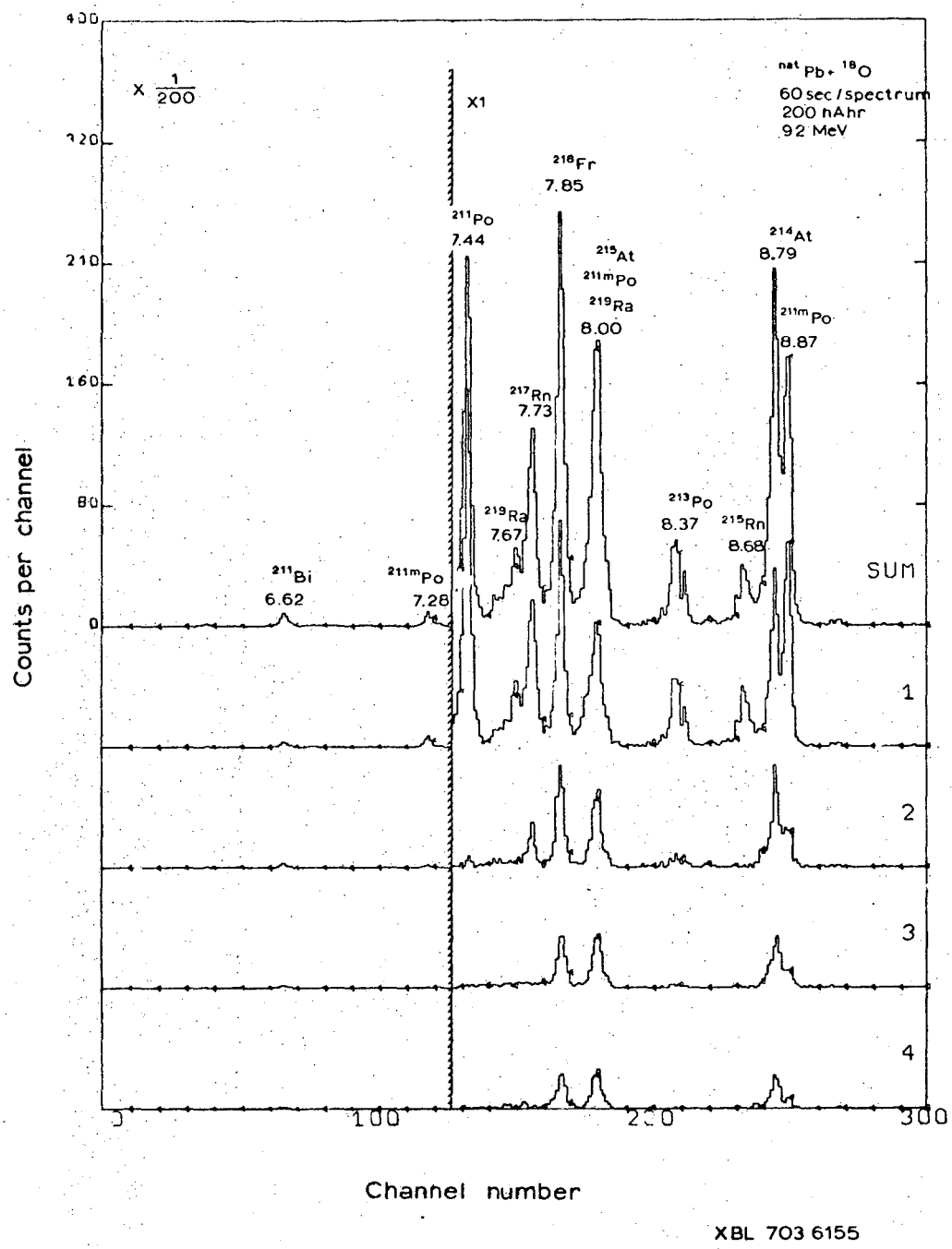
CBB 698-5321

Fig. 1



XBL 7036153

Fig. 2



XBL 703 6155

Fig. 3

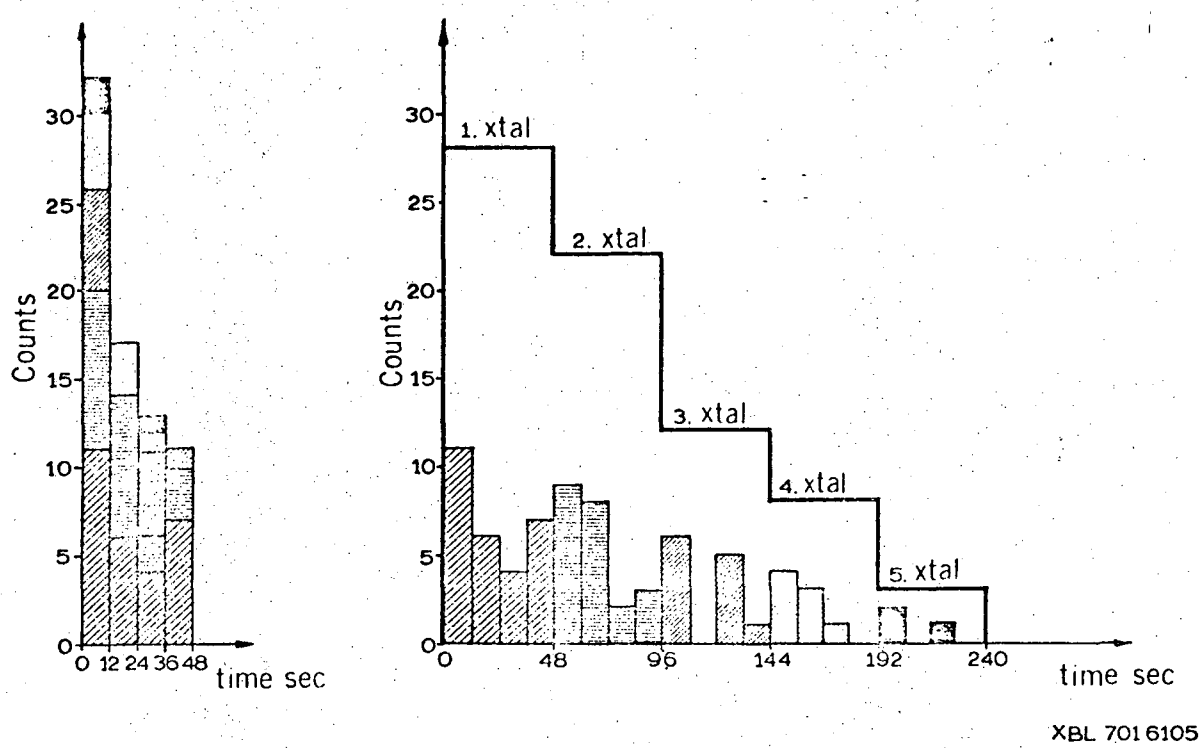

$^{248}Cm + ^{18}O$ 122 μA hrs
Observed daughter counts at 8.2 – 8.4 MeV energy
Counts
time sec
1. xtal
2. xtal
3. xtal
4. xtal
5. xtal
XBL 7016105

Fig. 4

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