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ELEMENT 106†

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Abstract:

We have produced element 106 by bombarding ^{249}Cf with ^{18}O ions accelerated by the SuperHILAC. The new nuclide $^{263}106$, produced by the $^{18}O,4n$ reaction, is shown to decay by α-emission with a half-life of 0.9±0.2 sec and a principal α-energy of 9.06±0.04 MeV to the known nuclide ^{259}Rf, which in turn is shown to decay to the known nuclide ^{255}No.

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The identification of new elements at the upper end of the periodic table is especially difficult because of extremely low production rates and because there are large uncertainties in predicting their nuclear properties. For these reasons, positive identification requires some means of determining the atomic number directly. Among the proven methods are (1) the measurement of distinctive K-X rays[1,2] following α-decay and (2) the establishment of a genetic link between an α-emitter of a new element and a previously identified daughter nuclide. Our identification of element 106 is based on the latter method because of its higher sensitivity. This method was also used in discovering α-emitting isotopes of rutherfordium (element 104)[3] and hahnium (element 105).[4] In the case of element 106, we have carried this method one

step further by demonstrating that the granddaughter (^{255}No, $t_{\frac{1}{2}}$ = 3 min, E main alpha group 8.11 MeV (57%))[5,6,1] is in the chain of α-decay of ^{263}106. Thus, our proof for the atomic number of element 106 comes from demonstrating the following decay sequence: $^{263}106 \xrightarrow{\alpha} {}^{259}Rf \xrightarrow{\alpha} {}^{255}No \xrightarrow{\alpha}$.

These genetic relationships were established in two ways depending on whether or not the ^{263}106 α-particles escaped from their backing surface. (1) In the case where these particles were detected leaving the surface we observed with a certain probability in a time interval of 12 seconds the alphas of the 3-second daughter ^{259}Rf (E_α = 8.77 and 8.86 MeV) that also were directed outward; i.e., we observed the $^{263}106 \xrightarrow{\alpha} {}^{259}Rf \xrightarrow{\alpha}$ decay sequence. (2) In the case where the ^{263}106 alphas were directed into the backing surface (and hence were not detected), the recoil energy imparted to the daughter nucleus allowed it to escape from the surface and to be implanted in the face of an opposing detector. Upon periodically moving these detectors away from the original sources, the α-decay of daughter ^{259}Rf and the subsequent α-decay of the granddaughter were observed; i.e., we detected the $^{259}Rf \xrightarrow{\alpha} {}^{255}No \xrightarrow{\alpha}$ decay sequence. Considering the finite thickness of the deposits containing the ^{263}106 atoms, the considerable recoil energy required to transfer the observed number of daughter ^{259}Rf atoms to the detector faces could be furnished only by a preceding α-emitter. We thus were provided with a second genetic linkage to ^{263}106 by α-decay.

Our experimental apparatus is illustrated schematically in Fig. 1. The ^{18}O beam obtained from the SuperHILAC had an average current of 3×10^{12} ions/sec and was wobbled electromagnetically over the target area to prevent localized overheating of the target. The target was both edge-cooled by contact with a water-cooled copper block and gas-cooled by helium impinging on the aluminum target backing. The energy of the ^{18}O ion beam emerging from the target was

determined by measuring the energy of these ions scattered from the target into a Si(Au) surface barrier detector placed at 30° to the beam axis.

The target was prepared by subliming 259 μg of ^{249}Cf as CfF_3 onto a 27 $\mu g/mm^2$ substrate of 99.999% pure Al. The ^{249}Cf, deposited over a 6.3-mm diam. area had an average surface density of 8.3 $\mu g/mm^2$. It was covered with a thin (0.3 $\mu g/mm^2$) layer of Al to prevent any transport of the californium to the detection system.

Atoms of $^{263}106$ along with other transmutation products recoiled from the target into a stopping chamber and were swept by a flow of helium through Teflon tubing (4.8 m. long, 1.24 mm inside diam.) into an adjoining counting area. The introduction of NaCl aerosol into the helium increased the transport efficiency to 80 percent or more. After a 0.1 sec transit time, the radioactive products which emerged from the Teflon tube were deposited onto the rim of a 45-cm diam. wheel which was rotated 45° each sec to collect a new deposit. Alpha particles from the deposits were then examined by a series of seven detecting stations each having 50-mm^2 Si(Au) surface barrier detectors positioned within 0.5 mm of the wheel rim. An eighth 100-mm^2 Si(Au) annular detector analyzed the α-activity of the deposit while it was being collected. Thus, each deposit was α-analyzed for seven sec (1 sec at each station) before it returned to the collecting position. Since new deposits were layered over the old, the wheel was advanced by 1.5° every 30 min to reduce the buildup of long-lived radioactivities in the deposits being analyzed.

If an α-particle from the decay of $^{263}106$ is observed, then another α-particle from the decay of its daughter, ^{259}Rf, should follow within a few daughter half-lives. Both events must originate from the same deposit, but they may be observed in separate detectors because the wheel advances the

deposit every second. After considering the counting geometry and the decay and gating intervals we calculated a detection efficiency for these "mother-daughter" pairs of 28 percent compared to "mother only" events.

In addition to monitoring mother and daughter α-decays directly, we used a detector shuttle system (shown in the inset of Fig. 1) to detect daughters and granddaughters resulting from α-recoils. By moving the detectors away from the wheel, we could distinguish between recoil-implanted and wheel-borne ^{255}No and ^{259}Rf. Much larger amounts of these nuclides were made by direct nuclear reactions than by α-decay from ^{263}106 and thus constituted a high background on the wheel. The set of seven detectors monitoring the wheel was shuttled every 6 sec to a low-background position facing seven stationary detectors, while another set of movable detectors resumed the monitoring of the wheel. In the event that a ^{259}Rf daughter had recoiled from the wheel onto a detector and we later observed α-decay of this daughter with the detector in the off-wheel position, this detector was not returned to the wheel position until 10 minutes had elapsed. This time period permitted an adequate opportunity for observing the subsequent α-decay of the 3-min granddaughter, ^{255}No.

Alpha and fission pulses from the detectors were amplified and passed through an analog-to-digital-converter to a PDP-9 computer. The computer recorded on magnetic tape all the event information, including α-energy, time, detector location, and wheel position. The PDP-9 also controlled the operation of the wheel and shuttle systems. We used off-line computer programs for correlating the arrival time of selected α-events with the time, α-energy, and detection location of other α-events. Using events in the ^{259}Rf energy region to define time origins, the intervals of 0 to 12 seconds and 50 to 62

seconds preceding these events were scanned for correlated decays. The first time range gave possible mother-daughter correlations, the second provided a good measure of the accidental background.

Earlier experiments performed in the Berkeley laboratory in 1970-71 had shown several promising mother-daughter events and daughter recoils. However, because of background radioactivities arising from Pb, Bi and Be in the target, these experiments were unable to provide sufficient proof of the atomic number. Our current α-spectra are virtually free of these background activities and show prominently only those α-emitters produced from the reactions of ^{18}O ions with ^{249}Cf.

The gross α-spectrum above 8 MeV, summed using the data from the wheel detectors, is shown in Fig. 2(a). Alpha groups at 8.77 and 8.86 MeV have been identified previously as belonging to ^{259}Rf.[3] We attribute most of the 87 events in the groups at 9.06 MeV and near 9.25 MeV to the α-decay of the new nuclide, $^{263}106$. When the number of these events observed at each wheel position (1 sec intervals) is plotted (Fig. 3) they are seen to decrease with a 0.9±0.2 second half life.

The 9.06 and 9.25 MeV alphas are followed within 12 seconds by daughter alphas at 8.77 and 8.86 MeV, as shown in Fig. 2(b). The ratio of the time-correlated daughters to gross $^{263}106$ events is roughly equal to the detection efficiency we derived for this process. An application of Poisson statistics indicates that, with 95% confidence, a maximum of 2.5 out of fourteen $^{263}106$-^{259}Rf decay pairs might be attributed to accidentals. Random alphas occurring 50-62 sec before ^{259}Rf decay events are shown in Fig. 2(c). We infer from these data that the new activity decays by emission of 9.06 and 9.25 MeV α-particles to ^{259}Rf and, therefore, can belong only to $^{263}106$.

Some 22 atoms of recoil-transferred ^{259}Rf were observed to decay in the off-wheel detectors. Shortly after such daughter events, granddaughter ^{255}No α-particles were detected in about a fifth of all off-wheel daughter decays. Considering the small number of granddaughters, this ratio may be expected from the ∿ 70 percent counting geometry and the ∿ 50 percent E.C. branching by ^{255}No.[7] In Table I we give a summary of all daughter-granddaughter and mother-daughter events.

From the rate of producing our new activity with α-energies of 9.06 and 9.25 MeV, we calculate a formation cross-section of ∿ 0.3 nb at an ^{18}O energy of 95 MeV. Very little of this activity was made by ^{18}O-ion beams of ∿ 91 and ∿ 100 MeV, which indicates a rather narrow excitation function. These preliminary measurements are consistent with our calculated excitation function for the ^{249}Cf (^{18}O,4n) reaction, which shows a half-width of 7 MeV and a maximum cross section of 0.2 nb.[8]

Spontaneous fission of ^{263}106 could not be determined because of interference from 2.7-hour ^{256}Fm, a spontaneous fission emitter produced in the bombardments. However, spontaneous fission is apparently not a major decay mode, since the α-events we observe account for a production cross section already larger than the calculated one.

During a recent visit by Soviet scientists to our laboratory, in which we exchanged information about "106" experiments, G. N. Flerov of the Dubna Laboratory reported the observation of spontaneous fission activities with half-lives of 4-10 milliseconds produced by bombarding ^{207,208}Pb with ^{54}Cr.[9] They attribute these activities to element 106. In view of the simultaneity of the experiments at the Dubna and Lawrence laboratories, and their very different nature, we shall postpone suggesting a name for element 106 until

the situation has been clarified.

Acknowledgements

This rather complicated experiment would not have been possible without the continued cooperation of several important groups. It is a pleasure in particular to make the following acknowledgements: to C. A. Corum, J. Meneghetti, and the Mechanical Technicians at the SuperHILAC for the design and fabrication of the apparatus; to R. G. Leres for his ingenious advanced data acquisition systems; to A. A. Wydler and others for the extensive electronic hardware used; and to the SuperHILAC operations and maintenance staffs for their diligence in providing many hours of reliable beam operation.

FOOTNOTES AND REFERENCES

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TABLE I

Mother-Daughter Correlations

$^{263}106$ E_α (MeV)	^{259}Rf E_α (MeV)	$^{263}106$ Station	Δt (sec) ^{259}Rf decay
9.03	8.85	1	3.6
9.04	8.85	2	10.5
9.04	8.91	1	1.2
9.05	8.74	2	2.2
9.05	8.77	5	0.9
9.05	8.85	1	1.0
9.06	8.70	2	3.0
9.06	8.72	1	2.5
9.06	8.75	3	1.6
9.06	8.78	1	6.4
9.06	8.78	3	9.4
9.08	8.74	1	2.1
9.08	8.76	7	0.3
9.25	8.88	1	3.5

Daughter-Granddaughter Correlations

^{259}Rf E_α (MeV)	^{255}No E_α (MeV)	^{259}Rf Station	Δt (sec) ^{255}No decay
8.79	8.02	2	93.3
8.86	7.93	6	134.9
8.81	8.30	2	39.2
8.81	8.07	1	491.0

FIGURE CAPTIONS

Fig. 1 Schematic representation of the experiment.

Fig. 2(a) Sum of alpha spectra from stations 1 through 7. The integrated beam intensity was 1.34×10^{18} particles of ^{18}O.

Fig. 2(b) Alpha events in the 0-12 second interval preceding ^{259}Rf events (8.65 to 8.91 MeV). The 12 second time interval represents four ^{259}Rf half lives.

Fig. 2(c) Alpha events in the 50-62 second interval preceding ^{259}Rf events. A 50-second time displacement was chosen to determine the accidental spectrum. Only one alpha event was found within the $^{263}106$ energy region, as had been expected from Poisson statistics.

Fig. 3 Alpha decay curve of the $^{263}106$ isotope in the energy region of 9.02 to 9.29 MeV (data from Fig. 2(a)). The small long-lived background is due to a tail from the spontaneous fission activity of ^{256}Fm.

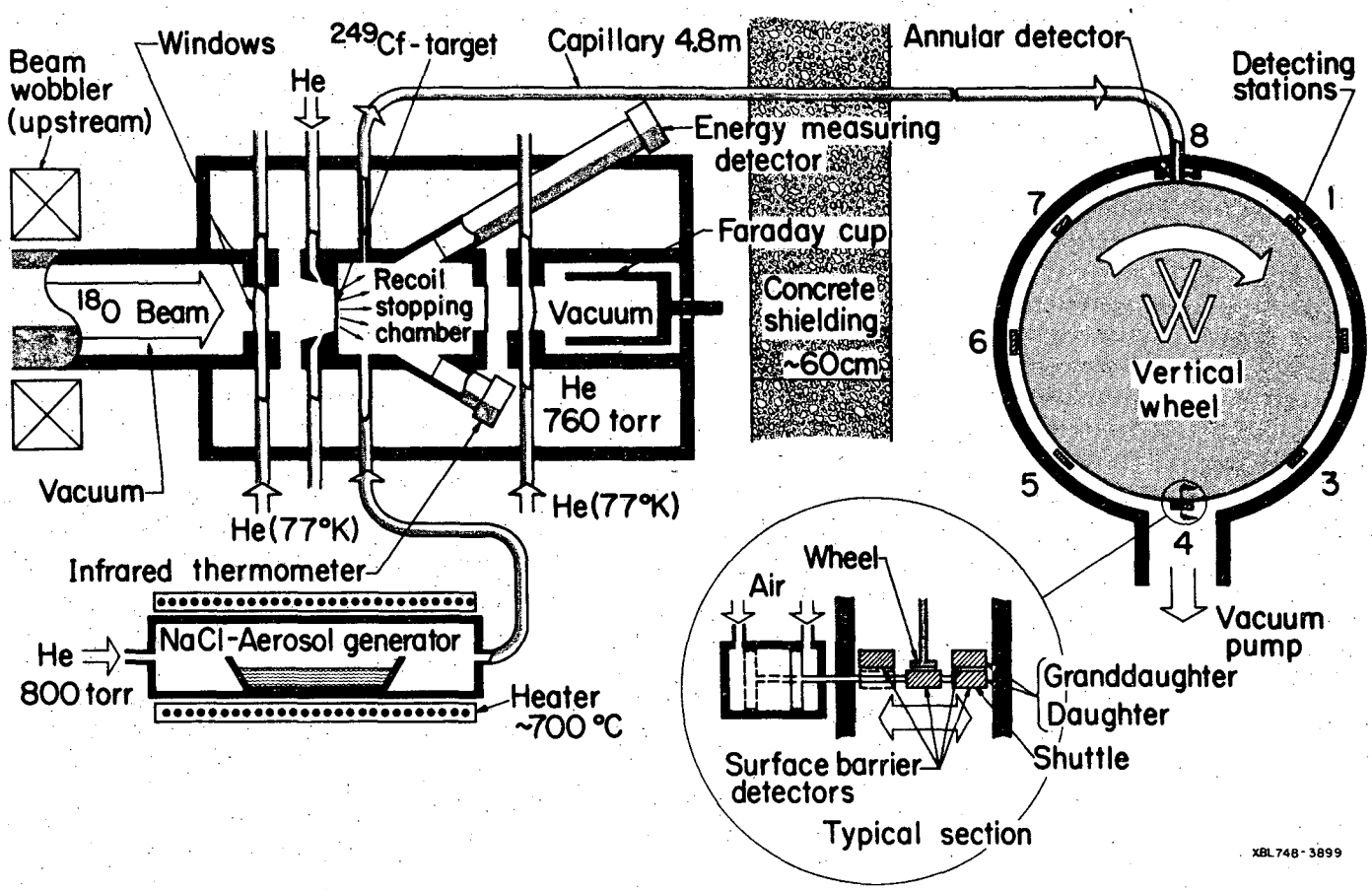
Beam wobbler (upstream)
Windows
He
249Cf-target
Capillary 4.8m
Annular detector
Detecting stations
Energy measuring detector
Faraday cup
Concrete shielding ~60cm
18O Beam
Recoil stopping chamber
Vacuum
He 760 torr
Vacuum
He(77°K)
He(77°K)
Infrared thermometer
He 800 torr
NaCl-Aerosol generator
Heater ~700 °C
Vertical wheel
Vacuum pump
Wheel
Air
Granddaughter
Daughter
Shuttle
Surface barrier detectors
Typical section
XBL748-3899

Fig. 1

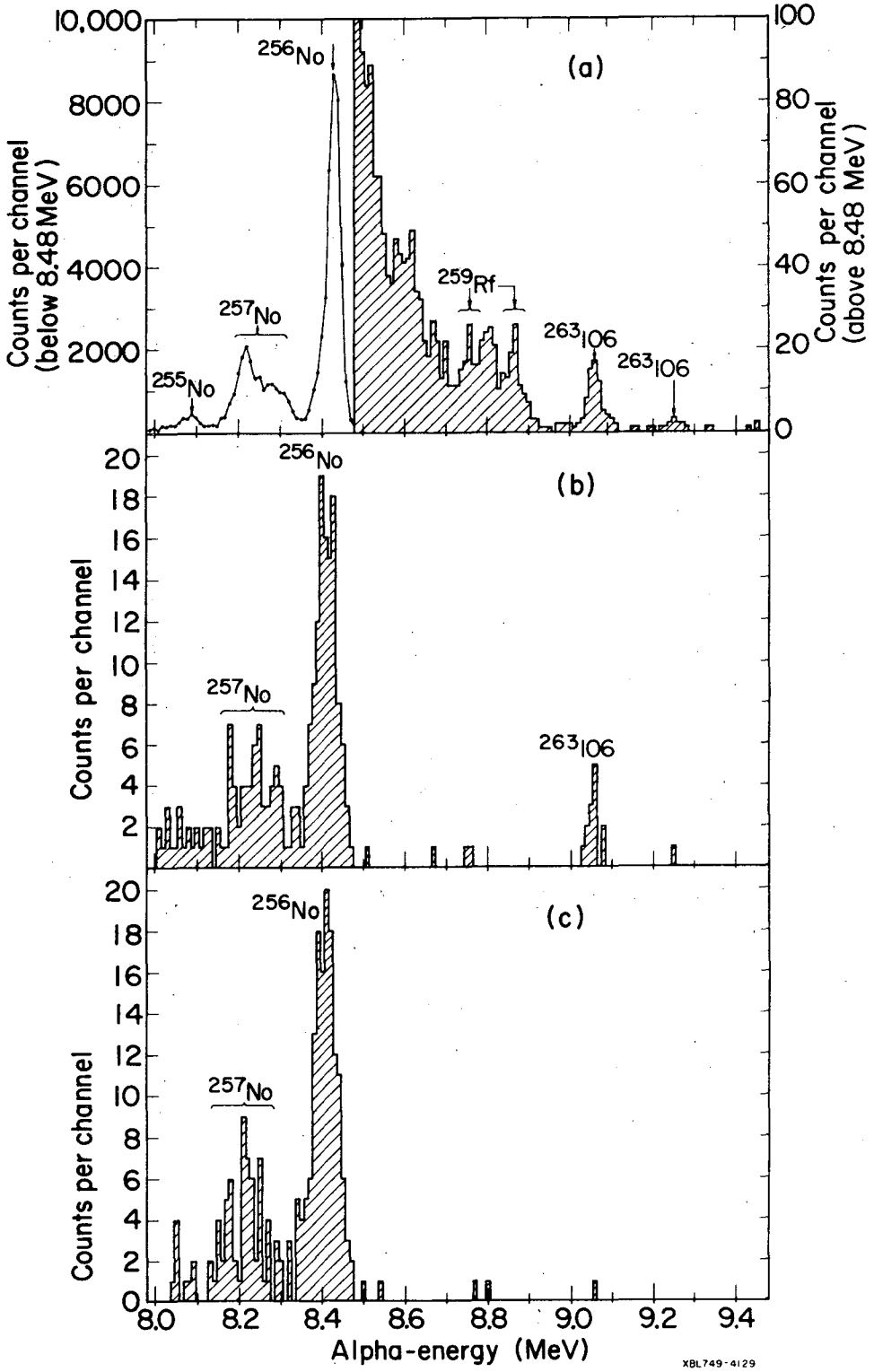
10,000
8000
6000
4000
2000
Counts per channel (below 8.48MeV)
100
80
60
40
20
0
Counts per channel (above 8.48 MeV)
(a)
256No
257No
255No
259Rf
263106
263106
(b)
256No
257No
263106
Counts per channel
(c)
256No
257No
Counts per channel
8.0
8.2
8.4
8.6
8.8
9.0
9.2
9.4
Alpha-energy (MeV)
XBL749-4129

Fig. 2

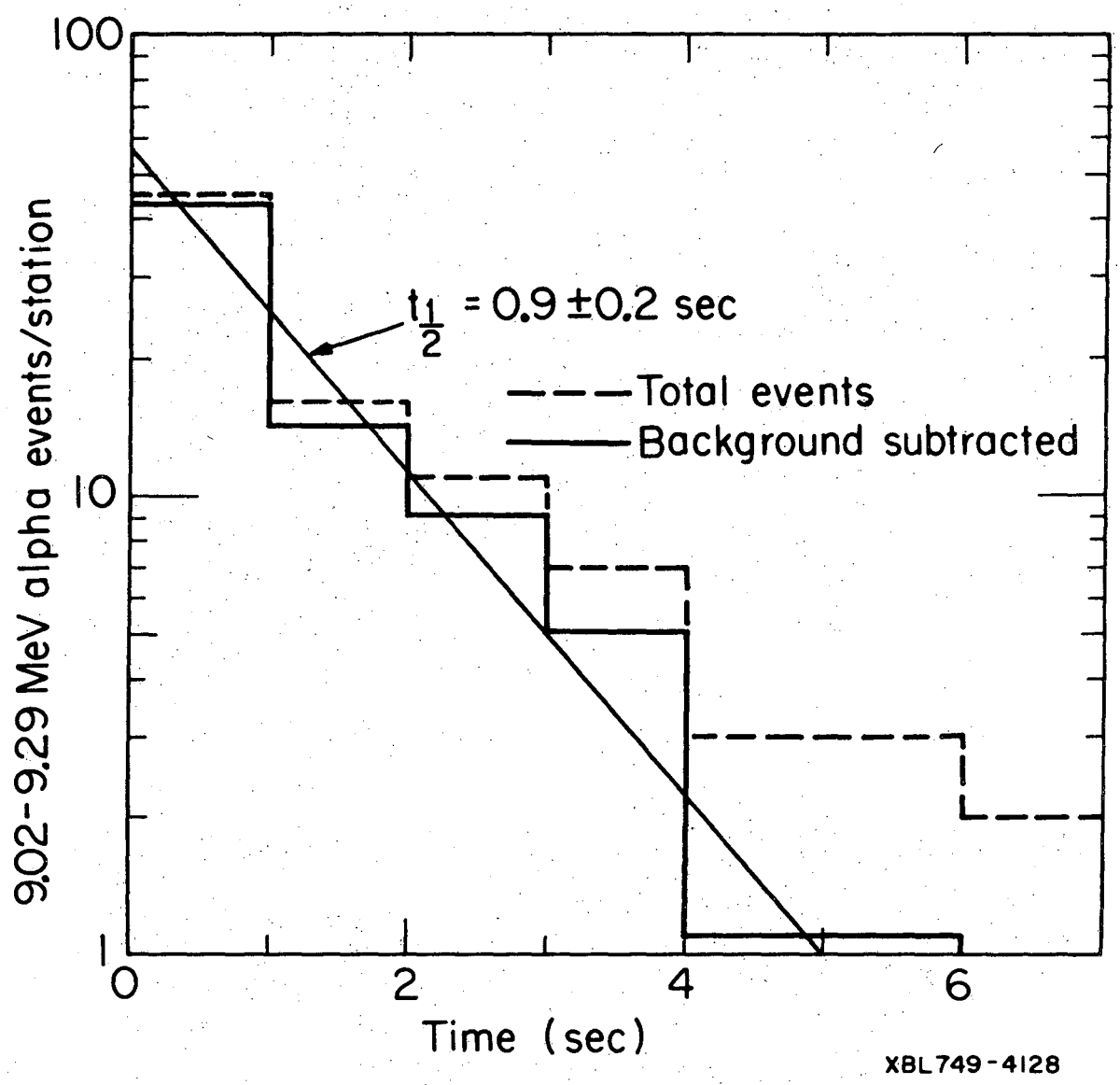
100
10
1
9.02-9.29 MeV alpha events/station
$t_{\frac{1}{2}}$ = 0.9 ±0.2 sec
Total events
Background subtracted
0
2
4
6
Time (sec)
XBL749-4128

Fig. 3

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