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[19]It must be emphasized that Eq. (5) is deliberately truncated so as to display only the essential features of the reversible polarization and strain components of the FE phase. Other important terms and a discussion of the elastic and dielectric response are given in Ref. 5.

[20]The solution in Region I of Fig. 3 corresponds to a base-centered orthorhombic phase which is *non*polar since $Q_x Q_y = 0$. There seems to be no evidence for such a phase for RE molybdates. This solution is, however, rather closely related to the transformation which occurs in ADP ($NH_4H_2PO_4$).

Spontaneous-Fission Half-Life of ^{258}Fm and Nuclear Instability*

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A spontaneous-fission activity decaying with a half-life of 380 ± 60 μsec, identified as ^{258}Fm, was discovered among the recoil products from the bombardment of ^{257}Fm with 12.5-MeV deuterons. The sharply decreasing spontaneous-fission lifetimes of nuclei with $N > 152$ show a determined trend contrary to theoretical predictions. The exceedingly short half-life of ^{258}Fm has led us to conclude that even-even nuclei in the immediate region beyond $N = 158$ are becoming catastrophically unstable toward fission.

As shown in Fig. 1, the spontaneous-fission half-lives of nuclei with neutron numbers greater than 152 decrease rapidly with increasing N (nuclei with more than 157 neutrons were unknown until now). Because of the perturbation introduced by the 152-neutron subshell, theoretical extrapolations of spontaneous-fission (SF) lifetimes for nuclei with neutron numbers above 156 are contradictory and allow the possibility of a recovery of stability at this level. Since theory was hopeful while the trend of experimental half-lives was pessimistic, it became important to search for an even-even nuclide well past the 152-neutron subshell.

Our search centered upon ^{258}Fm since we believed the fissionability of a nucleus containing 158 neutrons would not be influenced by the localized effect of the 152-neutron subshell. Thus, the SF half-life of ^{258}Fm would serve as an important guide to the nuclear stability of even heavier nuclei. We expected the principal mode of decay of ^{258}Fm to be spontaneous fission, since we estimated the SF half-life to be less than 2 h while systematics indicated a 70-200-day partial half-life for α decay.

Many experiments designed to identify ^{258}Fm were performed over a period of five years. Previously we made attempts to detect the spontaneous-fission decay of this nuclide in fermium chemically separated from the debris of thermo-

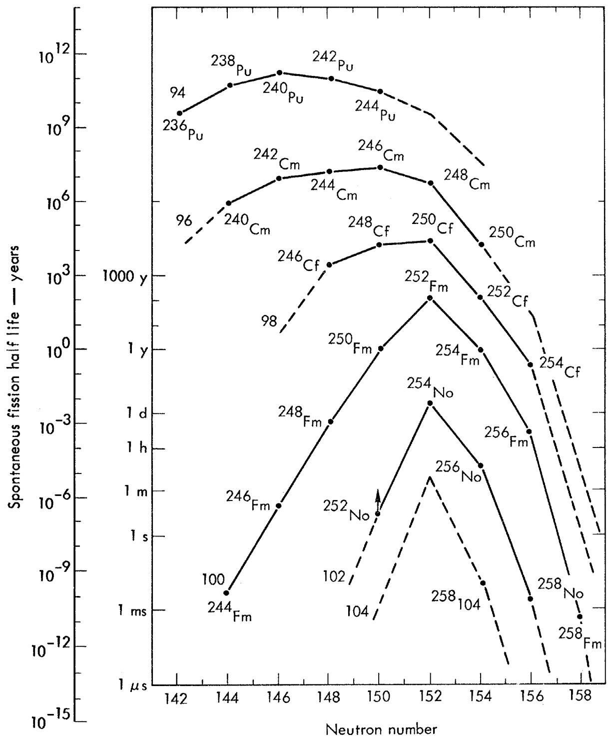

FIG. 1. Systematics of the spontaneous-fission half-lives of even-even isotopes of the heaviest elements.

nuclear explosions,[1] in reactor-produced fermium, after electron-capture decay of ^{258}Md,[2] and from short neutron irradiations of ^{257}Fm.[3] No fission events assignable to ^{258}Fm could be detected in these experiments, although it was shown that the half-life was greater than 50 years or less than 0.2 sec, if formed with a 1-b cross section from ^{257}Fm.[3]

In the experiments we are now reporting, ^{258}Fm was produced in the (d,p) reaction by the bombardment of ^{257}Fm with 12.5 MeV deuterons. The quantities of ^{257}Fm needed to make such bombardments successful were unavailable until the "Hutch" thermonuclear test which produced a total of 0.25 mg of ^{257}Fm.[4,5] A very small fraction, 5×10^9 atoms of ^{257}Fm, was chemically separated from ~10 kg of rock debris after the explosion. After extensive chemical purifications, a weightless sample was isolated which was electroplated onto a 0.013 mm-thick beryllium foil giving a 2.2 mm diam target.

The fermium target, facing away from the incoming beam, was clamped into a water-cooled collimating assembly containing aluminum degrading foils which reduced the energy of the Berkeley heavy-ion linear-accelerator (HILAC) deuteron beam from 20.4 to 12.5 MeV. The target assembly together with the detection system, schematically shown in Fig. 2, were enclosed in an evacuated box connected with the HILAC beam tube.

The technique[6] for detecting spontaneous-fission events from the decay of ^{258}Fm required the collection of ^{258}Fm recoil atoms on the rim surface of a large drum rotating at high speed. Surrounding and facing the drum surface were stationary strips of muscovite mica in which only fission tracks are recorded. The atoms of ^{258}Fm were caught and carried on the surface of the drum until they decayed, leaving a track in the mica which was readily identified at 200× magnification, after etching in hot hydrofluoric acid. In these experiments, we used a 25-cm-diam drum rotating at a preset frequency between 1500 and 3275 rpm with a gap of 0.8 mm between the surfaces of the mica and drum.

The bombardments and recording of fission

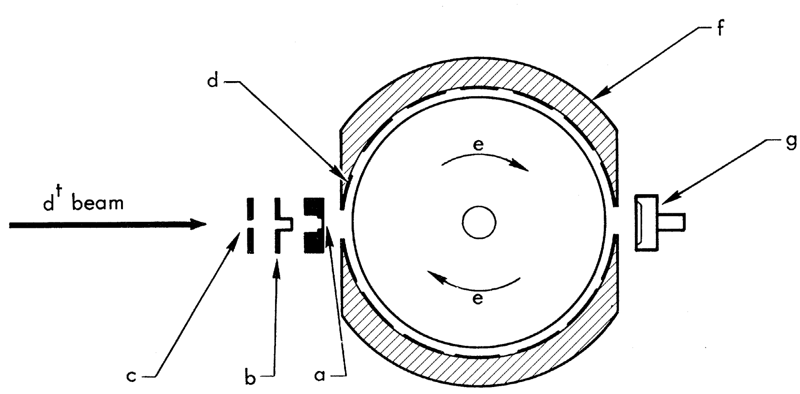

FIG. 2. Schematic of target and drum-mica system. Deuterons strike the ^{257}Fm target (a) after passing through aluminum degrading foils (b) and tantalum collimator (c). The atoms of ^{258}Fm recoiling from the target are caught on the surface of rotating drum (e) and their decay by SF is recorded in short strips of mica (d) attached in a continuous band to drum housing (f). An α detector (g) was used for monitoring the recoil efficiency of the targets.

tracks were continuous for 8-16 h, at which point the mica strips were recovered, etched, and scanned for characteristic fission tracks. The half-life was determined by the exponential decay of the number of fission events with circumferential distance from the target. A time base is provided by calculating the surface velocity of the drum at a noted shaft rpm.

We were initially troubled by overwhelming backgrounds caused by the neutron fission of natural uranium in metal parts adjacent to the mica strips. These problems were eventually overcome by reducing the number of neutrons, generated by deuteron breakup in beryllium degrading foils, by changing to aluminum degraders and using tantalum beam collimators. A further reduction of the background was obtained by constructing a drum of stainless steel in which the steel was especially selected and analyzed for low uranium content. Ultimately, the uranium content of the mica (~0.2 parts per billion) limited any further improvement in the background, which averaged ~30% of the ^{258}Fm fissions.

Because of the very low recoil energy given to the ^{258}Fm atoms by the incoming neutron from the (d,p) reaction, extra precautions were required to produce and maintain a very "thin" ^{257}Fm target. To monitor the recoil efficiency, we incorporated into the fermium targets several nanograms of ^{210}Pb separated from radon. Alpha particles from the decay of ^{211}Bi, formed after the beta decay of the (d,p) product, ^{211}Pb, were continuously counted by a Si (Au surface barrier) detector (g in Fig. 2) facing the drum surface at 180° opposite the target port. About 40% of the total atoms made were caught on the drum surface after a freshly prepared target was bombarded for 10 h with a total of 35 μA h of deuterons. After many such bombardments, this recoil efficiency decreased to 6% because of metal sputtering from the drum onto the target surface and from the decomposition of organic vapors in the vacuum on the thermally hot target.

A total of 680 net fissions were counted in five bombardments (see Fig. 3). In every experiment, the half-life was found to be within 380 ± 40 μsec although the drum speed was changed from one experiment to the next, with the lowest speed being 1500 rpm and the highest 3275 rpm. No fissions other than background were observed at 75 rpm. Between the fourth and fifth bombardment, the target was chemically repurified from all actinide elements and the 380-μsec SF activity was found again in undiminished yield. We

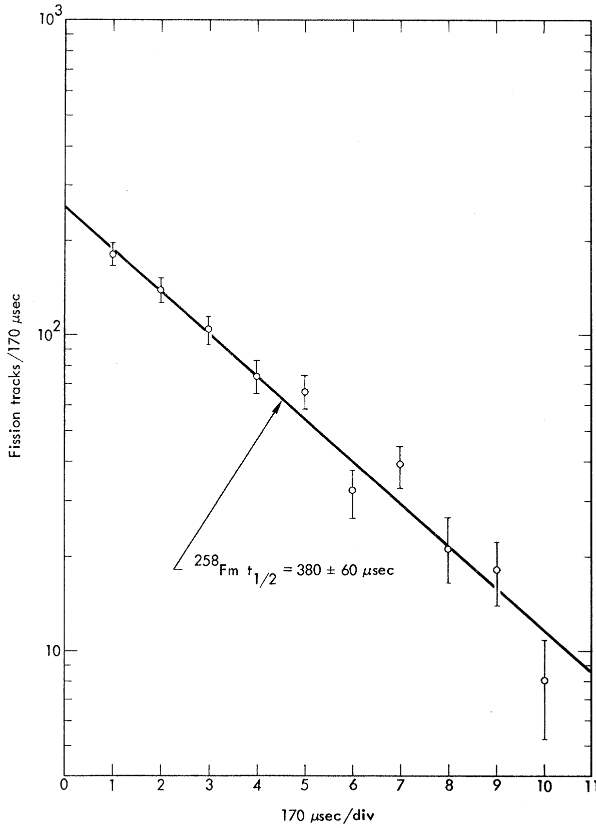

FIG. 3. Decay curve for spontaneous fissions assigned to ^{258}Fm. Net fission tracks from five bombardments have been summed.

have concluded this activity can belong only to ^{258}Fm, since it was produced from the ^{257}Fm targets and not from a similar target containing 10^{10} atoms each of ^{257}Fm daughters (^{249}Bk, ^{249}Cf, ^{253}Es) mixed with 42 ng of uranium and 0.1 ng of ^{239}Pu.

A cross section of 35 mb was measured for the formation of ^{258}Fm with 12.5-MeV deuterons. This cross section is consistent with known (d,p) cross sections for fissile targets which average ~50 mb when bombarded with 11-13-MeV deuterons.[7] It is also 10-30 times larger than cross sections expected for compound-nucleus reactions with deuterons, thereby excluding products from reactions such as (d,n), $(d,2n)$, etc. Lastly, we believe fission isomers are very unlikely since their formation cross sections by (d,p) reactions are typically less than 2 μb.[7,8]

In summary, a 380 ± 60-μsec (3σ) SF activity belonging to the ground-state decay of ^{258}Fm has been identified. This activity could be produced only through the bombardment of ^{257}Fm with deuterons and not by similar bombardments of uranium, ^{239}Pu, ^{249}Bk, ^{249}Cf, and ^{253}Es. A formation cross section of 35 mb is consistent with a (d,p) reaction, but it is many times too large for reactions leading to products other than ^{258}Fm. A half-life of 380 μsec is much shorter than the limit established in previous experiments (0.2 sec) and it is, therefore, consistent with all our earlier work.

The exceedingly short half-life of ^{258}Fm has led us to conclude that heavier even-even nuclei are becoming catastrophically unstable toward fission. Therefore, it seems unlikely that many such nuclei with $N > 158$ will be identified in the future until a region is reached where filling of the next proton or neutron shell (^{298}114?) will add a necessary measure of stability. We further conclude that reactor production of heavy isotopes will cease at ^{257}Fm and that although thermonuclear explosions, such as the "Hutch" experiment, may have produced heavier nuclides, these were not detected in the debris[4,5] because of their excessively short SF lifetimes. Finally, we note that theoretical predictions of SF lifetimes fail to forecast the severe shortening of half-lives for neutron-rich isotopes. Figure 1 shows that the experimental fission half-lives, at a constant Z, attain a maximum at or near beta stability and decrease symmetrically with decreasing or increasing neutron numbers. The divergence between theoretical and measured values becomes especially serious for even-even nuclei well beyond the 152-neutron subshell. As an example, the difference amounts to $\geq 10^8$ for ^{258}Fm, when our half-life is compared to the estimates of Johansson,[9] Viola and Wilkins,[10] and Nilsson *et al.*[11] In view of such large discrepancies, we conclude that the fission barriers calculated from single-particle effects superimposed upon the liquid-drop model are not realistic for estimating half-lives. In particular, the neutron number seems to have little influence upon the barrier heights (deformation energy) of the heavier isotopes of the transplutonium elements. This lack of strong neutron dependency, within the Nilsson formulation,[11] may arise from misplacing the position of the neutron levels or from underestimating the reduction in surface energy of a liquid drop caused by neutron-proton asymmetry at the nuclear surface.

We are pleased to acknowledge the excellent support of the HILAC staff and operating crew and to thank Cristina Jung for scanning many of the mica strips for fission tracks. We would especially like to acknowledge the vital work by Roland Quong, Hugh Wilson, Wesley Hayes, John Cowles, and Melvin Coops in separating ^{257}Fm from the bulk of the "Hutch" rock debris.

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