TABLE I.

Neutron-reaction	Maximum neutron-energy	Uranium		Thorium	
		No Cd	With Cd	No Cd	With Cd
	Mev				
Li+D	13.5	100	70	100	100
D+D	2.5	100	70	100	100
C+D	0.5	100	10	0	0

With the amplifier feeding a cathode-ray oscillograph the usual alpha-particle pulses were observed when a layer of uranium oxide was placed on the disk. On exposure to neutron-radiation from (Li+D) at 1000 kv two additional groups of pulses were observed. The first group corresponded to the "neutron-recoils" from the air in the chamber, as previously measured with the same amplifier gain and without the uranium. These neutron-recoils gave pulses about four times the size of the alpha-particle pulses. The second additional group was 20 to 40 times larger than the largest "recoil"-pulse, thus corresponding to energies of 75 to 150 Mev released in the chamber, or 150 to 300 Mev total energy for each individual process. With paraffin surrounding source and chamber the yield was roughly 30 counts per min. per μA of 1000-kv deuterons, which is a neutron-intensity corresponding to about 10,000 millicuries of radon-beryllium. The yield from thorium was of the same order of magnitude.

No effect was observed from bismuth, lead, thallium, mercury, gold, platinum, tungsten, tin or silver with as much as 1/1000 the intensity of that from uranium and thorium.

No effect was observed with either uranium or thorium produced by the gamma-rays from 3 μA of 1000-kv protons on lithium or on fluorine.

To determine roughly the energy-range of the neutrons involved in the fission-process, observations were made with the neutrons from several reactions, both with and without cadmium surrounding the ionization-chamber to filter out the thermal neutrons produced in the surrounding paraffin. Bearing in mind that the ratio of the counts with cadmium and without cadmium depends to a large extent on the amount of paraffin surrounding the source and chamber, the results of these tests may be deduced from Table I in which the relative number of "fissions" is given, with the total yield for uranium and thorium with high energy neutrons, being approximately equal, taken as 100 on an arbitrary scale.

From these comparisons it appears that the uranium fissions are produced by different processes for fast and slow neutrons, the fast-neutron process requiring more than 0.5 Mev but less than 2.5 Mev for effective operation. For thorium, on the other hand, only the fast-neutron process is effective, but somewhat surprisingly it also appears to require between 0.5 and 2.5 Mev.

R. B. ROBERTS
R. C. MEYER
L. R. HAFSTAD

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.,
February 4, 1939.

Heavily Ionizing Particles from Uranium

After reading in local papers of Hahn's discovery of the splitting of uranium into heavy elements, we wired Professor Gamow for further details. He answered that Tuve had observed the heavily ionizing particles in a differential linear amplifier chamber. We have confirmed this by using a thin ionization chamber, one of whose plates was covered with U, or U_3O_8. With a certain gain, the U natural alphas gave two-mm kicks on an oscilloscope, Po alphas passing parallel to the plates gave eight-mm pulses, and the Hahn-Tuve particles gave deflections of four cm. The energy released in a path length of less than 0.5 mm was about 10 Mev, so the particles must carry several charges, and therefore be "heavy." Check runs on Pb, Cu, Zn, W and Th showed no such bursts. After confirming the existence of these particles, we investigated the type of reaction responsible. A thin Cd covering around the chamber reduced the counting rate to less than five percent. This is unexpected in view of the fact that about half of the "transuranic" activity is due to resonance neutrons which could penetrate Cd. This result shows that Hahn's effect is due largely to thermal neutrons. By the use of a modulated beam of neutrons, we have looked for a time delay in the emission of heavy particles, after the neutron irradiation. The time delay is less than 3×10^{-3} sec. Our thanks are due Professor E. O. Lawrence for his interest in this experiment, and the Research Corporation for financial support.

G. K. GREEN*
LUIS W. ALVAREZ

Radiation Laboratory,
Department of Physics,
University of California,
Berkeley, California,
January 31, 1939.

* National Research Fellow.

Intensely Ionizing Particles Produced by Neutron Bombardment of Uranium and Thorium

We have bombarded uranium nitrate and also thorium oxide with deuteron-deuteron neutrons in a three-millimeter brass ionization chamber and found particles producing an intense ionization. We attribute the results to extremely high energy particles of roughly half the mass of the bombarded nucleus, and believe that they confirm the recent work of Hahn and Strassmann[1] and of Frisch and Meitner[2] on uranium, and also establish a similar effect with thorium.

The substance was bombarded in the form of a layer (about 0.5 gram) stuck with collodion on a paper disk three centimeters in diameter and placed in contact with a mesh-covered opening into the ionization chamber. The gain of the oscilloscope was set so that the kicks resulting from the natural alpha-radiation were about one centimeter high. During neutron bombardment kicks of height greater than five centimeters (peak outside the field of vision) were observed. These were counted visually. Counts were made at various deuteron beam intensities with the chamber directly under the neutron source and also about a meter away, with paraffin and without paraffin

TABLE I. *Number of counts per minute of heavily ionizing particles from the bombardment of uranium and thorium with deuteron-deuteron neutrons for deuteron currents of 0.5 and 1.0 ma at 250 kv.*

	No paraffin		Paraffin	
	i = 1.0 ma	0.5 ma	i = 1.0 ma	0.5 ma
U	35	—	69	38
Th	21	11	20	—

around the chamber. Also background counts were made with no uranium or thorium and ran consistently zero over five-minute periods.

Results are given in Table I. The numbers represent counts per minute and are the means of five to ten observations for each case. The paraffin effects in the table were obtained with paraffin around chamber but not between chamber and neutron source. Placing paraffin between source and chamber reduced the counts for uranium to 34 per minute.

The ionization due to nitrogen and oxygen ions produced by neutrons was approximately the same as that due to the natural uranium alpha-particles. Our linear amplifier did not possess a calibrated gain variable over sufficiently wide limits to enable us to determine accurately the ionization produced by the heavy particles. However, on removing one stage of amplification, we were still able to observe the kicks due to heavy particles, and therefore we believe the ionization due to the heavy particles is at least one hundred times that produced by the alphas or recoil ions.

Thus the effect is obtained with 2.4-Mev neutrons for both thorium and uranium. Paraffin doubles the yield for uranium but has no effect on that for thorium. The reality of the effect is confirmed by its proportionality to the intensity of the deuteron beam.

The apparatus used in this research was constructed with the aid of a grant from the Research Corporation.

R. D. Fowler
R. W. Dodson

Chemical Laboratory,
Johns Hopkins University,
Baltimore, Maryland,
February 3, 1939.

[1] Hahn and Strassmann, Naturwiss. January, 1939.
[2] Frisch and Meitner, Private Communication from Dr. M. A. Tuve. We are informed by Dr. Tuve that Frisch and Meitner have also observed this effect with thorium on or about January 16, 1939.

Cleavage of the Uranium Nucleus

We have been studying what seemed to be L x-rays from the seventy-two-hour "transuranic" element. These have now been shown by critical absorption measurements to be iodine K x-rays. The seventy-two-hour period is definitely due to tellurium as shown by chemical test, and its daughter substance of two-and-a-half-hour half-life is separated quantitatively as iodine. This seems to be an unambiguous and independent proof of Hahn's hypothesis of the cleavage of the uranium nucleus.

Philip Abelson

University of California,
Berkeley, California,
February 3, 1939.

Resonance in Uranium and Thorium Disintegrations and the Phenomenon of Nuclear Fission

The study of the nuclear transmutations by neutron bombardment in uranium and thorium, initiated by Fermi and his collaborators, and followed up by Meitner, Hahn and Strassmann, and by Curie and Savitch, has brought to light a number of most interesting phenomena. Above all, as pointed out by Meitner and Frisch,[1] the recent discovery of Hahn and Strassmann of the appearance of a radioactive barium isotope as the product of such transmutations offers evidence of a new type of nuclear reaction in which the nucleus divides into two nuclei of smaller charges and masses with release of an energy of more than a hundred million electron volts. The direct proof of the occurrence of this so-called nuclear fission was given by Frisch[2] for thorium as well as for uranium by the observation of the very intense ionization produced in a gas by the high speed nuclear fragments.

In a recent note[3] commenting on the ingenious suggestions put forward for the explanation of the fission phenomenon by Meitner and Frisch, the writer has stressed that the course of the new type of reactions, just as that of ordinary nuclear reactions, may be assumed to take place in two well-separated stages. The first of these is the formation of a compound nucleus, in which the energy is stored in a way resembling that of the heat motion of a liquid or solid body; the second consists either in the release of this energy in the form of radiation or in its conversion into a form suited to produce the disintegration of the compound nucleus. In the case of ordinary reactions, resulting in the emission of a proton, neutron or α-particle from this nucleus, we have to do with a concentration of a considerable part of the excitation energy on some particle at the nuclear surface, sufficient for its escape, which resembles the evaporation of a molecule from a liquid drop. In the case of the fission phenomena, the energy has to be largely converted into some special type of motion of the whole nucleus causing a deformation of the nuclear surface sufficiently large to lead to a rupture of the nucleus comparable to the division of a liquid drop into two droplets. From considerations of statistical mechanics analogous to those applied to the evaporation-like nuclear disintegrations, it follows indeed that the probability of occurrence of fission becomes comparable to that of ordinary nuclear reactions when, with increasing nuclear charge, the deformation energy concerned has decreased to values of the same order of magnitude as that demanded for the escape of a single particle.

Here I should like to show how such considerations would seem to offer a simple interpretation of the peculiar variation with neutron velocity of the cross sections of the different transmutation processes of uranium and thorium observed by Meitner, Hahn and Strassmann.[4] In the light of the new discoveries, the great variety of processes obtained, which could not be disentangled on the ordinary ideas of nuclear disintegrations, would seem, according to Meitner and Frisch, to be reduced to only two types of transmutations. Of these the one consists in an ordinary radiative capture of the incident neutron, resulting in the