Letters to the Editor

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Atomic Energy from U^{238}

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THE recent experiments of Nier, Booth, Dunning, and Grosse[1] and of Kingdon, Pollock, Booth, and Dunning[2] have confirmed Bohr's prediction[3] that the nuclear fission produced in U by thermal neutrons is to be attributed practically entirely to the rarer isotope of mass 235. This is present in an amount only 1/139 as great as that of the 238 isotope, so it is natural to conclude that only 1/140 of any quantity of U can be considered as a possible source of atomic energy if slow neutrons are to be used. It seems likely, however, that this is wrong, that the energy of a large part of the U^{238} nuclei can also possibly be made to undergo fission by slow neutrons in an indirect way. This is of obvious importance for practical utilization of the atomic energy of U.

The indirect use of U^{238} can come about through the fission either of the U^{239} nuclei formed by the capture of neutrons, or of the nuclei descending from U^{239}. In a forthcoming paper[4] it is shown that ${}_{93}EkaRe^{239}$ and ${}_{94}EkaOs^{239}$, the probable long-lived descendants from U^{239}, would be expected to undergo fission upon capture of thermal neutrons. A similar argument leads to the conclusion that U^{239} itself would probably also give fission with thermal neutrons. For such fission to be of consequence it is necessary that nearly one U^{239} atom be produced for every U^{235} atom lost. That this condition can be satisfied may be seen as follows. Consider N secondary neutrons. A number Np will suffer resonance capture by U^{238} to give U^{239}, p being the probability for such capture. The remaining $N(1-p)$ neutrons will become thermal. Of these, $N(1-p)w$ will produce fission of U^{235} nuclei and $N(1-p)(1-w)$ will be captured by U^{238} nuclei, w being the probability that a thermal neutron will produce fission. It is assumed that no other capture processes are important for the thermal neutrons, that a non-capturing method of slowing the neutrons needed for developing the divergent chain reaction has been found. The total number of U^{239} nuclei formed is thus $Np+N(1-p)(1-w)$ and the number of U^{235} nuclei lost is $N(1-p)w$. The condition that every U^{235} nucleus be replaced by a U^{239} or descendant nucleus becomes $Np+N(1-p)(1-w)>N(1-p)w$ which reduces to $1/(1-p)>2w$. Since $w<1$ this condition can be met if $p\sim 0.5$ as it was in the experiments of Halban, Joliot, Kowarski, and Perrin.[5] Presumably it can be made so with other methods of slowing down the neutrons. Some concentration of the U^{235} isotope may be necessary if p is to be ~ 0.5. Since the number of neutrons evolved per fission[5] is ~ 3 the divergent chain can develop if more than one on the average gives fission and the present condition be satisfied if more than one gives U^{239}.

It seems likely, however, that of the three nuclei ${}_{92}U^{239}$, ${}_{93}EkaRe^{239}$, and ${}_{94}EkaOs^{239}$ only the last might be expected to have a large cross section for fission. The excess energy in the ${}_{92}U^{240}$ and ${}_{93}EkaRe^{240}$ nuclei after capture of neutrons by ${}_{92}U^{239}$ and ${}_{93}EkaRe^{239}$, respectively, would be small compared to what it is in the ${}_{92}U^{236}$ nuclei coming from ${}_{92}U^{235}$. The cross sections for fission would thus be correspondingly small. In ${}_{94}EkaOs^{240}$, on the other hand, the excess energy would be even larger than in ${}_{92}U^{236}$ and a large cross section for fission would be expected. It might thus be necessary to allow U from which the ${}_{92}U^{235}$ had been used up to lie idle for several times the as yet unknown half-life of ${}_{93}EkaRe^{239}$ until a sufficient quantity of ${}_{94}EkaOs^{239}$ had developed in it, after which it could again be used. This could be repeated until all of the ${}_{92}U^{238}$ had been converted.

* This letter was received for publication on the date indicated but was voluntarily withheld from publication until the end of the war.
[1] Nier, Booth, Dunning, and Grosse, Phys. Rev. **57**, 748 (1940).
[2] Kingdon, Pollock, Booth, and Dunning, Phys. Rev. **57**, 749 (1940).
[3] N. Bohr and J. A. Wheeler, Phys. Rev. **56**, 426 (1940).
[4] L. A. Turner, Phys. Rev. **57**, 951 (1940).
[5] Halban, Joliot, Kowarski, and Perrin, J. de phys. et rad. **10**, 428 (1939). See also L. A. Turner, Phys. Rev. **57**, 334 (1940).

Radioactive Element 94 from Deuterons on Uranium

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WE are writing to report some results obtained in the bombardment of uranium with deuterons in the 60-inch cyclotron.

The uranium was bombarded in the form of U_3O_8 and the deuterons had to pass through a 2-mil thickness of aluminum foil before hitting the uranium target. The carefully purified element 93 fraction contained a beta-activity whose aluminum absorption curve (taken on an ionization chamber connected to an FP–54 tube and also on a Lauritsen electroscope) was distinctly different from the absorption curve of a sample of the 2.3-day 93^{239} (formed from uranium plus neutrons) taken under identical conditions. The upper energy limit of the beta-particles from this new 93 activity is about 1 Mev, compared with about 0.5 Mev for 93^{239}. The ratio of gamma-ray to beta-particle ionization is about five times larger than for 93^{239} The initial part of the absorption curve of this 93 from uranium plus deuterons is very similar to the initial part of the absorption curve of 93^{239}. Of course the production of 93^{239} is expected in the deuteron bombardment of ura-