SYNTHESIS OF THE ELEMENT 102 OF MASS NUMBER 256

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An \( \alpha \)-active nuclide of the element 102 having mass number 256 has been synthesized in the nuclear reaction \( \text{U}^{238} (\text{Ne}^{22}, 4n) \text{No}^{256} \). The nuclide was recorded and identified through the daughter nuclide Fm\(^{252}\). The measured half-life of the nuclide No\(^{256}\) was found to be \( \approx 8 \) sec.

The energy dependence of the formation cross section of nuclide No\(^{256}\) in the \( \text{U}^{238} + \text{Ne}^{22} \) reaction was studied. It peaks in the 112 MeV region. The cross section is \( \approx 4.5 \times 10^{-22} \) cm\(^2\) in the area of the peak.

This work was carried out using the internal beam of the three-meter cyclotron of the Nuclear Reactions Laboratory, a subdivision of the Dubna Joint Institute for Nuclear Research.

INTRODUCTION

At the present time, the principal technique used to synthesize new transuranium elements involves nuclear reactions resulting in the bombardment of uranium, plutonium, americium, curium, californium, and einsteinium targets by intense fluxes produced by accelerated boron, carbon, nitrogen, oxygen, and neon ions. The reactions used predominantly have been fusion of the target nucleus and the nucleus of the bombarding ion with subsequent boiling off of several neutrons from the compound nucleus. The cross sections of those reactions in the region beyond the hundredth element are very small and constitute at most \( 10^{-29} \) to \( 10^{-33} \) cm\(^2\). The reason for this is the high energy of excitation of the compound nuclei formed in the reaction, and the high fissionability of those nuclei.

The products of these nuclear reactions—the far transuranium elements—are neutron deficient to a pronounced extent, and this renders their \( \alpha \)-decay time comparatively short. The low formation cross sections and the short decay times, as well as the large number of competing processes having higher probabilities, lead to the appearance of the most varied background activities in the products of interactions between these ions and the target nuclei, and are responsible for the difficulties encountered in producing and isolating new heavier elements. These difficulties increase still more precipitously as heavier and heavier elements are to be synthesized. This has stimulated the efforts of experimental physicists to search out still more effective ways of isolating new elements, bringing not only chemical but also physical techniques to bear on the problem of identifying trace quantities of new elements.

Experiments have been underway since 1957 on the synthesis of the element 102. During that time, findings of research projects conducted at laboratories in different countries have appeared in print. However, the actual proof of successful synthesis of element 102 to any extent as convincing as the evidence offered in connection with the synthesis of preceding elements has been lacking in the published reports.

The first communication on record on the synthesis of element 102 appeared in the summer of 1957 [1]. A team of scientists from Sweden, Britain, and the USA published a report on work which they carried out at the Nobel Institute of Physics in Stockholm. A curium target (isotope composition: Cm\(^{244}\) \( \approx 95\% \); Cm\(^{248}\) \( \approx 1\% \); Cm\(^{246}\) \( \approx 4\% \); Cm\(^{247}\) \( \approx 0.09\% \); and Cm\(^{248}\) \( \approx 0.02\% \)) was irradiated by C\(^{15}\) ions in a cyclotron installation with cyclotron pole diameter 225 cm. The products of the nuclear reactions were separated out, after the exposure, on a chromatographic column. As a result, weak \( \alpha \)-activity such that \( E_\alpha = 8.5 \pm 0.1 \) MeV and \( T_1^\alpha = 10 \) min was detected, the chemical behavior being what one would expect from theoretical prediction on element 102. The total number of recorded decay events apparently did not exceed 25.

On the basis of the data so obtained, the authors inferred that the observed \( \alpha \)-activity was due to an isotope of the element 102, of mass number 251 or 253. These isotopes may be synthesized in the reactions Cm\(^{244}\) (C\(^{15}\), 6 n) \( 102^{251} \) or Cm\(^{244}\) (C\(^{15}\), 4 n) \( 102^{253} \), respectively. It is not excluded that this activity may even belong to products obtained as a result both of spallation reactions and of reactions taking place on impurities in the target material.
was shown in other contributions to the literature [2-4], these processes have a sufficiently high rate to present a troublesome background. This is particularly the case when we remember that the chemical procedure utilized by the authors of [1] did not enable the researchers to reliably isolate element 102 from other elements present.

In February 1958, a staff team of the I. V. Kurchatov Institute of Atomic Energy published a paper describing an attempt to synthesize the nuclide No$^{253}$ wherein a physical method of identification was used [4].

The Pu$^{241}$ (O$^{16}$, 4 n) No$^{253}$ was decided upon for synthesizing the nuclide No$^{253}$. A Pu$^{241}$ target was bombarded by O$^{16}$ ions accelerated to 100 MeV energy in a 1.5 meter cyclotron. The nuclear reaction products knocked from the target were led to an α-particle detector, consisting of a nuclear emulsion stack. Short-lived α-activity of about 8.9 MeV energy, which might have been a result of the synthesis of one of the isotopes of the element 102 (and most probably of No$^{253}$, in fact), was detected in these experiments. The experiments were greatly hindered by the presence of a large amount of hitherto unknown α-emitters in the reaction products. It was shown that some of these α-emitters appear as a result of reactions taking place in lead, bismuth, and other elements present in the form of impurities in the target material.

The experiments were extended into 1958 [5]. Painstaking removal of all possible impurities and a specially developed highly sensitive activation analysis procedure used on the plutonium targets employed in the experiments revealed that the contributions of the impurities remained below 40%, and that the total background amounted to 50% of the observed effect due to the α-activity $E_\alpha = 8.9 \pm 0.4$ MeV. Experiments were designed and conducted to aid in identifying the product responsible for this α-activity.

It could be safely assumed, on the basis of the results of a study of the dependence of the yield of this reaction product on the energy of O$^{16}$ ions, that the product forms in a reaction having a typical excitation function for evaporative reactions. When Pu$^{239}$ targets are bombarded by oxygen ions, no yield of this product is observed. The results of the experiments on record back up the conclusion that the product responsible for this α-activity is indeed the nuclide No$^{253}$.

As a result of the experiments carried out in this project, the half-life of the element No$^{253}$ has been found to lie in the range 3-40 sec. The presence of background α-emitters, and in particular of an isomer of Pu$^{231}$ ($E_\alpha = 8.8$ MeV; $T_\frac{1}{2} = 25$ sec) produced in nuclear reactions which occur in the lead impurities present in the target, enabled us to determine no more than the lower and upper bounds of the half-life.

The discrepancy in the results reported in [1] and in [4, 5] may be accounted for by the fact that no unambiguous determination of the mass number of the synthesized nuclide was performed in the Stockholm experiments. The curium targets had a rather complicated isotope composition, and it is not at all excluded that the nuclide No$^{255}$ was synthesized in these experiments in the reaction Cm$^{244}$ (Cm, 4 n) No$^{255}$, or that some even heavier nuclide was formed [6]. However, Berkeley experiments have demonstrated on the other hand that this supposition lacks any substantial basis.

Experimental results on the synthesis of element 102 at the Radiation Laboratory of the University of California at Berkeley, on the linear heavy ion accelerator, were published in May 1958 [7, 8]. The experiments of the Stockholm group were repeated under similar conditions, but with much higher sensitivity. A curium target having the same isotope composition as that used in the Stockholm experiments was bombarded by a monochromatic beam of both C$^{13}$ ions and C$^{12}$ ions, while the ion energy was varied over a wide range. The accelerator beam intensity was many times in excess of the ion beam intensity of the Stockholm cyclotron. However, a careful and thorough investigation turned up no products of the family of nuclear reactions (C$^{12}$, x n) of α-activity $E_\alpha = 8.5$ MeV and $T_\frac{1}{2} = 10$ min. This provided once more a convincing demonstration of the fact that some important error must have crept into the work done at Stockholm.

Experiments on the synthesis of the shorter-lived isotopes of the element 102, in particular the nuclide No$^{254}$, were being carried out in California simultaneously with these above experiments [8]. The method used in these latter cases permitted investigators to record and identify the short-lived α-active isotopes in terms of their relatively short-lived daughters. In the case in point, No$^{254}$ was obtained in the reaction Cm$^{244}$ (C$^{13}$, 4 n) No$^{254}$, and was identified by the Fm$^{250}$ present (this is an isotope whose properties have been studied extensively). The half-life of No$^{254}$ was measured by this procedure, and found to be 3 sec. This work was completed with greater precautions than the preceding projects, and the fact of the synthesis of the isotope of element 102 having mass number 254 was backed up by sufficiently rigorous and airtight arguments.