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Will the End of the Actinide Series be Reached?

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The use of the high neutron flux in the Materials Testing Reactor at Arco, Idaho, has led to the production of readily observable amounts of elements 99 and 100. Recently it has been reported from the Radiation Laboratory of the University of California at Berkeley that the heaviest-to-date element 101, named Mendelevium in honor of the great 19th century Russian chemist, was made by bombarding element 99 with helium nuclei from the Crocker Laboratory 60-inch cyclotron.

According to Seaborg's original prediction, made in 1944, the actinide series will be completed at element 103. The next one, 104, will have chemical properties analogous to zirconium and hafnium, a sharp break from the rare-earth like preceding elements.

By repeated captures of neutrons in a reactor, it is possible to increase the mass of a nucleus until it spontaneously β^- decays to the next highest element. The process is then repeated, leading to reaction sequences such as the following:

$$Pu^{239} + 2n \rightarrow Pu^{241} \xrightarrow[\text{decay}]{\beta^-} Am^{241} + 1n \rightarrow Am^{242} \xrightarrow[\text{decay}]{\beta^-} Cm^{242}$$

$$Cm^{242} + 7n \rightarrow Cm^{249} \xrightarrow[\text{decay}]{\beta^-} Bk^{249} + 1n \rightarrow Bk^{250} \xrightarrow[\text{decay}]{\beta^-} Cf^{250}$$

$$Cf^{250} + 3n \rightarrow Cf^{253} \xrightarrow[\text{decay}]{\beta^-} 99^{253} + 1n \rightarrow 99^{254} \xrightarrow[\text{decay}]{\beta^-} 100^{254} .$$

It is by chains like this that Berkeley and the Argonne National Laboratories produce elements 99 and 100 in the Arco Reactor. In principle it is possible to continue this process of building-up until an isotope of element 100 is reached which β^- decays to 101. However, recent work at Arco by the Berkeley group shows that a new difficulty creeps in.

The isotope 100^{256} was found to have a very short half-life, only about 3 hours, and to decay by the spontaneous fission process. The nucleus has now become so unstable that it spontaneously splits into two roughly equal parts, and it does it so rapidly that there is little chance of capturing the next neutron to make 100^{257}.

Present estimates show that it will almost certainly be necessary to go up to 100^{259} before a beta decay to 101 will occur. The "block" at 100^{256} makes this difficult, and it seems likely that an even more serious "block" will occur at 100^{258}, which will probably have an even shorter half-life for spontaneous fission than 100^{256}.

However, other methods of making new elements have been investigated at Berkeley. By bombardment of uranium (element 92) with nuclei of nitrogen (element 7) accelerated in the cyclotron it was possible to make a few atoms of element 99. Both in Stockholm and Berkeley, element 100 was made by bombarding uranium with accelerated oxygen ions. In principle, element 102 could be made by bombarding plutonium (94) with oxygen (8), or element 104 by bombarding curium (96) with oxygen.

These experiments will not be easy. The amounts of these new elements may be measured in terms of only a few atoms. Their

radioactive decay will be rapid. All even-mass nuclei of even elements such as 102 and 104 will probably decay very rapidly by spontaneous fission. The plutonium and curium targets will be intensely radioactive and difficult to handle. Conventional methods of proof of the discovery of new elements by solution chemistry may have to be abandoned as too slow, but there will remain physical methods based both on nuclear and extra-nuclear properties, and these should be perfectly adequate to prove whether or not element 104 shows the anticipated sudden change in chemical properties.

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