

pond to maximum change in isotopic composition but to zero change at the peak. I would point out to Andrews that valid conclusions cannot be drawn from calculations which fail to take precipitation into account.

The isotopic evidence demonstrates that there was a massive flood in the Gulf of Mexico, peaking about 11,600 years ago. Since nature is self-consistent, I suggest that those who have commented on our report revisit their tunnel valleys and spillways to look for the matching evidence.

With respect to Plato and the "Atlantis Connection," I refer the reader to (6).

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References and Notes

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7. Only 3 weeks were allowed by the editors of *Science* for the preparation of this reply. Since my co-authors of (3) are presently scattered from Florida to Taiwan, it was impossible to contact them. This reply, therefore, is necessarily written by the senior author alone. I am grateful to G. Maul for discussions on the eastern Gulf Loop Current. Financial support was provided by the National Science Foundation (grants GX36155, GA36189X, and DES 74-23459).

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Criteria for the Discovery of Chemical Elements

The availability of suitable heavy-ion accelerators in a number of laboratories in Europe and the United States should make it possible to synthesize and identify additional heavy transuranium elements. The predicted small yields of such nuclides require identification of atomic number to be made with individual atoms. This places a large burden on the experimenter and can lead (and in fact has led) to differences of opinion as to the extent of experimental proof required to establish definitely that the production of a new element has been observed. There is also the possibility that superheavy elements may be found in natural sources. We attempt here to define criteria for adequate proof that a new element has been synthesized or found in nature, and identified—that is, discovered.

The basic criterion, of course, must be the proof, by some means, that the atomic number (Z) of the new element is different from the atomic numbers of all previously known elements. This means, in general, that the atomic number should be established. It should not be necessary to establish the mass number, except insofar as this evidence is directly related to the method used for establishing the atomic number.

Chemical identification constitutes an ideal proof that an element with a new atomic number has been produced. Two important requirements should be met in this kind of experiment. First, the chemical procedure should be of a type that is valid for application to individual atoms; the use, for example, of ion exchange

adsorption-elution or partition between solvents has been shown to meet this criterion in many situations, and such methods also provide safeguards against complicating surface adsorption and entrainment effects. Second, it must be possible to determine the presence or absence of the new element in the appropriate chemical fractions in an unequivocal manner. If the new element is observed through its decay by high-energy alpha-particle emission or spontaneous fission, or both, the chemical identification can be confined to separation from all known elements with atomic number greater than lead ($Z = 82$).

Unfortunately, chemical identification is not always feasible in the initial experiments, as demonstrated by the reported discoveries of the last several synthetic elements; this circumstance has contributed significantly to the competing claims for the discovery of these elements. (No such differences of opinion have arisen over the discoveries, based on chemical identification, of mendelevium and earlier transuranium elements.) Fortunately, there are methods based on the observation and use of nuclear properties that should be adequate to furnish unambiguous identification of atomic number.

Also satisfactory is the identification of characteristic x-rays in connection with the decay of the isotope of the new element. In actual practice this is likely to involve measurement of the half-life and precise, unique energies of the alpha particles of the new element in coincidence with the characteristic x-rays of

the daughter nuclide. However, it might be possible to measure characteristic x-rays of the new element itself (primary product) if these can be associated with the subsequent immediate decay of this nuclide. Thus, such short-lived x-rays, which may be emitted in the course of, or as an aftermath of, the production of the primary product, might be followed very shortly by emission of alpha particles or fission fragments which could be detected by delayed coincidence techniques. The characteristic x-rays must, of course, be distinguished from gamma rays of similar energies—perhaps by identification of the complex structure of the x-rays.

The proof of a genetic decay relationship through an alpha-particle decay chain in which the isotope of the new element is identified by the observation of previously known decay products should be acceptable. This method depends on measurement of the half-life and precise, unique energies of the alpha particles of the new isotope, and measurement and identification of the half-life and decay properties of the daughter, whose identity, including atomic number, has been previously established. Time correlation between parent and daughter should be established. Use of a genetic relationship as evidence for a new element implies that the mass number of the new element isotope is experimentally determined by its relationship to a daughter nuclide of known mass number.

Detection of a spontaneous fission activity and measurement of its half-life cannot per se establish that an element with a new atomic number has been produced. Even when additional information, such as fragment mass and kinetic energy distributions, can be obtained, the atomic number assignment for new elements cannot be made on this basis alone since the systematics and theoretical predictions cannot be extrapolated with the necessary certainty into new regions. Similarly, the use of the predicted half-lives for spontaneous fission decay and alpha decay and of predicted alpha-decay energies cannot yet be considered sufficiently reliable for establishment of the atomic number of a new element.

The present understanding of production yields, excitation functions, angular distributions, and so forth is not sufficient to allow measurements to establish with certainty that a nuclide with a new atomic number has been produced, although such data may be useful as supportive evidence. It is particularly difficult to establish and interpret the

difference between heavy-ion-induced compound nucleus reactions in which only neutrons are emitted (and consequently the atomic number of the product nucleus is the sum of the atomic numbers of the target and projectile) and those nuclear reactions (compound nucleus or otherwise) in which charged particles (such as protons and alpha particles) are also emitted so that the atomic number of the heavy product is less than the sum of projectile and target atomic numbers. An unambiguous differentiation between these reaction mechanisms would be necessary for the proof of atomic number by the use of such techniques. Information from cross bombardments can be useful, but again, interpretation of the results is subject to the same uncertainties concerning production yields and reaction mechanisms.

Special mention should be made of some anticipated features of the identification of the so-called superheavy elements, the elements expected to occupy the "island of stability" centered around nuclides with "magic numbers" such as $Z = 114$ and $N = 184$ (N is the number of neutrons in the nucleus), or $Z = 126$. It is quite possible that nuclides in this region of Z and N might be observed to have such distinctive radioactive decay properties that it would be clear that one or more nuclides with new atomic numbers have been produced, even though exact atomic numbers cannot immediately be established. Such hitherto unobserved decay characteristics might consist of spontaneous fission fragments of uniquely large kinetic energy, perhaps high neutron multiplicity, or decay chains of uniquely high-energy alpha-particle emitters (possibly including members that undergo beta decay or terminate the chain with spontaneous fission decay). Mass determination could unambiguously establish the mass number in the superheavy element region. The observation of spontaneous fission activity which is chemically separable from the actinides and near transactinides should be sufficient evidence to establish that the atomic number is in the superheavy element region. Such observations should constitute adequate evidence that

one or more new elements have been discovered. In such cases, subsequent investigations may be required to establish the precise atomic numbers of the nuclides involved. Naturally, observation of characteristic x-rays could again be adequate here and would by itself constitute discovery of a new element provided, as mentioned before, the characteristic x-rays are identified and satisfactorily distinguished from gamma rays. These x-rays might be emitted in a decay process or induced by some method of excitation.

Mere first observation of a radioactivity without proof of its atomic number historically has not been considered sufficient to constitute discovery. The requirement for adequate evidence at the time of publication of the claim to discovery can be illustrated by an interesting case history. In 1943 Kurbatov and Pool (1) reported the production, through proton bombardment of neodymium ($Z = 60$), of isotopes of the then unknown element with atomic number 61 having half-lives of 2.7 hours and 5.3 days. Subsequent work has shown that these radioactivities were correctly assigned to element 61; the 2.7-hour activity is known to be due to mass number 150, the 5.3-day activity to mass number 148. However, the assignment in 1943 of these activities to element 61 was based on inadequate evidence to permit proof of the assignment of atomic number. Two years later Marinsky *et al.*, during research on the wartime Plutonium Project, proved by chemical means that two fission products of uranium should be assigned to element 61; these isotopes were 3.7-year $^{147}\text{61}$ and 47-hour $^{149}\text{61}$, and the work was described in a postwar publication (2). The proposal in 1947 by the first team of investigators that element 61 be named "cyclonium" was not accepted, while the proposal by the second team of investigators in 1948 that it be named "promethium" was accepted the following year by the International Union of Pure and Applied Chemistry.

As a concluding thought, we suggest that composite nuclear systems that live less than about 10^{-14} second (the generally accepted upper limit for a compound

nucleus lifetime) shall not be considered as new elements. Nuclear molecular systems (those in which extranuclear electrons encompass two closely adjacent nuclei), which can be identified by their corresponding transitory x-rays, would also not qualify as new elements.

The criteria described here should be necessary and sufficient for proof of the discovery of a new chemical element. We believe that any claim to such a discovery should be published in a refereed journal with sufficient data to enable the reader to judge whether the evidence is consistent with such criteria. We further believe that even when these criteria are met, the name for a new element should not be proposed by the discoverers until the initial discovery is confirmed.

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