have devised a model that solves it, The key to their solution lies in taking into account that, although reactions 1, 2. and 3 as we have written them may represent what happens *at the site of a collision inside a nucleus,* the emerging neutron (proton) is likely to hit and trade places with a proton (neutron) while on its way out of the nucleus and produce another mass-11 nuclide, boron-11 (nitrogen-11). Thus, the carbon-11 nuclei that the chemist sees may be fewer than the total that were initially produced in the collision. They represent the cases where "nothing went wrong."

Another research interest of the nuclear chemists at LAMPF concerns the "exotic" nuclei produced when 800-MeV protons strike nuclei, especially heavy ones. This interaction yields a wide assortment of particles and nuclear fragments ranging from pions and neutrons to nuclei only a little lighter than the target. Among these fragments are nuclei, many of them still unidentified, that represent the extremes of what can exist at all. Some of them have a great excess of neutrons, so great that their last few neutrons are barely held; these are described as almost neutron-unbound or near the "neutron drip line." There exist other nuclei at the opposite extreme: severely deficient in neutrons and rich in protons, that is, almost proton-unbound, or near the "proton drip line." These exotic nuclei are hard to find, Not only are they produced very rarely in nuclear reactions, but they have half-lives so short (seconds or less) that they cannot be isolated and identified by conventional radiochemical techniques. A team of nuclear chemists devised a method to identify some of these exotic products in flight, that is, as they emerge from the proton/heavy nucleus reaction. Measuring a product's time of flight from the production site to a detector gives its velocity: measuring its kinetic energy as it is stopped in the detector then gives its mass from the expression $E = \frac{1}{2}mv^2$ (the correction for relativistic effects is small); and measuring its rate of energy loss in the detector assembly gives its nuclear charge. Thus, by electronic means one establishes the identity of the isotope without chemically separating it or measuring its decay. In a series of experiments using thin targets of uranium and nickel, the nuclear chemists have identified five new examples of neutron-rich exotic isotopes: neon-27, magnesium-31, magnesium-32, aluminum-34, and phosphorus-39. (The heaviest stable isotopes of these elements are neon-22, magnesium-26, aluminum-27, and phosphorus-31.) Others are currently under study.

Present nuclear theory cannot predict accurately the boundaries of nuclear existence. and there is now evidence that even the exotic nuclei named above may be short of the neutron drip line, To illustrate this point, we pick an example from low-atomic-number nuclei measured elsewhere. The element beryllium, with an atomic number of 4, has a single stable isotope. beryllium-9. The question has been asked, "What is the heaviest possible isotope of beryllium?" A team at the University of California Bevatron made a search, employing an experiment similar to the one described above. At the upper end of the mass scale they found evidence for beryllium-11, -12 (both already known), and -14, but not for beryllium-13, -15, or -16. Thus, it appears that the neutron drip line occurs beyond beryllium-14 and that beryllium-16 is probably neutron-unbound. On the other hand, beryllium-11 is probably the heaviest odd-mass beryllium isotope that is neutron-bound. The difference between the odd- and even-mass isotopes is not surprising to nuclear scientists: it reflects the well-known preference of nuclear particles to occur in pairs.

The Discovery of Thorium-236

About a year before LAMPF's experimental program was officially launched with the production of the first mesons in 1973, the nuclear chemists conducted an experiment, Experiment Zero, that led to the first scientific discovery and publication from this new installation. By bombarding a target of uranium-238 with the high-intensity 100-MeV proton test beam that had just become available, they produced a new heavy isotope of thorium, thorium-236. With short bombardments followed by fast radiochemical isolation and electromagnetic isotope separations, they were able to identify and characterize this previously unknown isotope. It decays by beta emission with a half-life of 37.5 minutes. ■

So far we have talked in terms of merely establishing the existence of exotic nuclei. The data would be much more valuable if they told in addition *how stable* such nuclei are. The Los Alamos team is now at work on a new apparatus that should provide this kind of information. It will still measure time of flight, but with sufficient precision to give a spectroscopically useful isotope mass, which is a direct measure of nuclear stability. When operational, the instrument should yield masses on at least thirty exotic nuclei with accuracies of 200 keV or better, a figure that should lead to a new kind of thinking