Uranium Enrichment: Laser Methods Nearing Full-Scale Test

Within 2 years the Exxon Nuclear Company, in collaboration with the Avco Everett Research Laboratories, hopes to begin to build a pilot plant for uranium enrichment with a laser process. The intentions of Exxon and Avco are the latest indication that laser technology offers a new and very attractive approach to the difficult problem of uranium enrichment. Earlier this year news of Israeli success at uranium isotope separation with a laser method came to light (*Science*, 22 March 1974), and just last month Atomic Energy Commission scientists at the Lawrence Livermore Laboratory reported success too. Rumor has it that the AEC scientists at Los Alamos are really ahead of their Livermore colleagues but are keeping the news secret. With several successful experiments now announced, there can be little doubt that laser methods for enrichment of small amounts of uranium are well within reach of the present technology. Now the questions are, what will be the cheapest reliable method for an industrial process, and what country or company will develop it first.

Exxon and Avco, who filed their first major patent in 1970 before the AEC program began, appear to be moving rapidly toward full-scale testing of a pilot production plant. "We've carried our effort through the research stages," said Raymond L. Dickeman, president of Exxon Nuclear Company, in a recent interview with *Science*. We're taking it out of the lab and into engineering scale mockups to investigate scale parameters." What about rumors that the Exxon-Avco venture already has a pilot plant in operation? "It's a matter of definition what you call a pilot plant," he said. "We'll be testing individual items of production scale equipment."

To get to the stage of building engineering scale mockups has required considerable investment, and any industrial group trying to perfect laser enrichment faces possible competition from an expanded AEC research program, budgeted at $10.7 million for fiscal 1975. At the present time, Dickeman says, the Exxon-Avco effort is comparable in magnitude to the one that the AEC has announced. "We are apprehensive that ultimately it will be difficult to justify private capital going into the program," he said. But other companies are reportedly pleased with the scope of the AEC research.

Enrichment is necessary because the principal fissionable isotope of uranium, ^{235}U, constitutes only 0.7 percent of natural uranium. Since natural uranium isotopes are almost identical in their chemical properties, methods based on different weights rather than chemical properties have been used to separate one isotope from another in the past. The United States, like most other countries, has used a method which separates ^{235}U because it diffuses through a porous barrier slightly faster than ^{238}U. Diffusion plants are expensive to build and operate, by any yardstick. A typical plant today would cost $2 billion to $3 billion and require at least 2000 megawatts of electric power. Facilities to generate power for such a plant would cost another $1 billion at today's prices.

Tunable Dye Laser Is the Key

Rapid developments in laser technology now make it possible to utilize subtle differences in chemical properties that do exist among isotopes of the same element for uranium enrichment. With one of several tunable dye lasers that can now be purchased from U.S. companies, ^{235}U atoms can be forced into an excited state while accompanying ^{238}U atoms are left unaffected. Then some method, based on the fact that only one isotope is excited, must be used to isolate ^{235}U. In the Livermore experiment and the Exxon-Avco patents, the excited ^{235}U atoms are ionized and then deposited on a charged collector, but many other methods are possible. But some laser scientists think that methods employing ionization may prove to be the most expensive, as was the case with the Calutron, the magnetic apparatus that first separated uranium during World War II. The easiest method to demonstrate in the laboratory was far from being the most economical.

The edge that lasers have over other uranium enrichment methods, including the just-emerging centrifuge technique, is that extremely high levels of enrichment can be achieved in a single pass through a laser device. Whereas one stage in a gaseous diffusion plant only increases the concentration of ^{235}U by a few thousandths of a percent, the recent laser experiment at Livermore reportedly raised the ^{235}U concentration to 60 percent. With fewer stages the capital cost of the laser process is expected to be far less than that of a diffusion plant. Perhaps greater savings would result from reduced power consumption. Theoretically, as much as 99 percent of the power expended for gaseous diffusion could be saved with laser methods, and in practice at least 90 percent saving should be achieved. While cheaper uranium enrichment would not necessarily reduce the cost of nuclear power significantly, because fuel is a minor expense, it would give the country or company with low-cost enrichment technology a lucrative corner in an expanding market. This year, for the first time, the AEC expects to sell $1 billion in enrichment services.

The problem with laser enrichment is to find a method that is not only feasible in the laboratory, but workable and reliable and efficient at processing large quantities of uranium. The amount of ^{235}U produced in the Livermore experiment was apparently microscopic. Because of its spectral simplicity, atomic uranium vapor has been used in the experiments revealed so far, but it is a very difficult material to handle. Uranium must be heated to 2100°C, and it is then so corrosive that it destroys stainless steel. According to Benjamin Snavely at Livermore, "Uranium forms an alloy with every refractory material we know of. Then the apparatus just stops working." Uranium hexafluoride, rather than atomic uranium, is used in the diffusion and centrifuge separation processes, because it is not particularly corrosive and becomes a gas at 57°C. But the wavelengths at which uranium hexafluoride absorbs light overlap to such an extent that, according to D. Smith and R. Farrar in an unclassified AEC document published in 1972, laser isotope separation is probably impossible for uranium hexafluoride.

Other researchers question the conclusion that uranium hexafluoride is ruled out, noting that the data on its molecular properties used by Smith and Farrar were probably very crude compared to what can be learned now with laser techniques. But it seems clear that if a molecule containing uranium could be used instead of pure uranium, the

process would be much cheaper. Scientists working in the laser isotope separation project at Livermore are now analyzing a range of uranium compounds, probably including some newiy synthesized ones. The problem is to find a molecule with excited states that are less dense and overlap less than the states of uranium hexafluoride. For example, UF_5Cl might have a simpler spectrum than UF_6 because the replacement of one fluorine atom with chlorine would alter the molecular symmetry.

Besides the corrosiveness of uranium vapor, another problem with the Livermore process is that it is not very efficient. After the uranium vapor is produced in an oven "based on novel properties of uranium alloys," according to Snavely, it is illuminated with laser light at 5915.4 Å, a wavelength at which ^{235}U is relatively opaque but ^{238}U is transparent. (The corresponding absorption in ^{238}U occurs 0.1 Å lower.) At the same time, the stream of uranium vapor is bathed with an intense flood of ultraviolet light from an arc lamp (wavelengths 3000 Å or longer). The ultraviolet light is sufficiently energetic to ionize the ^{235}U atoms excited by the laser, but not the ^{238}U atoms. The ionized atoms are then deflected by an electric field and collected. One factor contributing to the inefficiency of the process is that the likelihood for the second step in the process to occur is three to four orders of magnitude less than for the first step. Another thing that tends to reduce the amount of ^{235}U actually produced is that the ionized atoms can become neutralized by collision with other gases, particularly ^{238}U, and thereby lose the charge identification tag that makes them separable. Excitation of the fissile isotope of uranium seems to be the easy part of an enrichment scheme. Keeping the excited molecules from transferring their energy before some physical or chemical process can be applied to isolate them appears to be more difficult.

Various processes besides the two-step ionization method can be used to separate isotopes, but they are not necessarily applicable to uranium compounds. V. S. Letokhov and R. V. Ambartzumian, at the Soviet Institute of Spectroscopy, Moscow, have reported separating ^{15}N from ^{14}N when the two isotopes are present in ammonia, by preferentially dissociating $^{15}NH_3$ with a two-step process. (The first photon excites NH_3 and the second dissociates it.) Researchers at Los Alamos recently reported success with the same technique for separating boron isotopes in BCl_3. In a two-photon process, photodissociation has the advantage over photoionization that the likelihood for absorption of the second photon is not so drastically suppressed. In some cases one-step dissociation is possible, however, so the problem of getting the second photon to be absorbed is circumvented. One-step dissociation of the deuterated component (D_2CO) of natural formaldehyde, which includes both H_2CO and D_2CO, was accomplished by C. B. Moore and E. S. Yeung at the University of California, Berkeley, and more recently Moore and Stephen Leone produced HBr enriched in the isotope ^{81}Br by a one-step dissociation of natural Br_2.

Another possibility is to find a chemical reaction that will proceed rapidly with the laser-excited molecules but not with the rest. So little is known about the chemistry of excited molecules that this approach has not yet been followed, but it could prove to be the cheapest method of laser enrichment.

Still another method is to try to make use of the small deflection undergone by the molecules that preferentially absorb laser light in order to separate them from the rest. A. Bernhardt and associates at Livermore recently showed that some separation of barium isotopes could be achieved by resonant scattering of laser light. A. Szoke at the University of Tel Aviv, Israel, and I. Nebenzahl have amplified this idea by suggesting that the laser light be reflected back and forth through the beam of vapor (uranium, for instance) several times. If the uranium vapor itself could be made to lase, absorbing a photon in one pass and reemitting it by stimulated emission on another pass, the deflection of the uranium atoms would be magnified, and in fact it might be possible to deflect more than one uranium atom per photon.

Almost all laser isotope separation schemes depend heavily on the detailed spectroscopic structures of molecules, first for finding suitable absorption frequencies and then for designing ways to physically separate the two species. Generally speaking, spectroscopic information with the resolution needed is not available in the literature, and can only be obtained by laser experiments. The best method, according to Snavely, will most likely be one that is particular to uranium, rather than a method generally applicable across the periodic table.

The AEC laser isotope separation program has been expanding rapidly in scope since it began in 1971. The Los Alamos program, called Project Jumper, has a staff of 90 and a budget of $5.6 million for fiscal 1975. Livermore's funding during the same period will be $3.1 million, and the staff will be at least 40. Only about a year ago, the total AEC research budget for laser isotope separation was said to be just over $1 million. At both laboratories, the laser enrichment programs are embedded in the much larger and also expanding laser fusion programs. They undoubtedly draw intellectual if not material support from the $66 million fusion efforts. One can surmise that laser enrichment efforts are not being expanded so rapidly without some solid progress in the research, although this could not be published in the scientific journals because most work on uranium enrichment is classified. A successful laser process for uranium enrichment could bring a bonanza to U.S. industry, if not a wealth of cheap energy, and some scientists are predicting that the AEC laser enrichment program will prove successful long before laser fusion does.—WILLIAM D. METZ

Control of Protein Synthesis (II): RNA in the Nucleus

Although the cytoplasm is the site of protein synthesis in the cell, new evidence tends to support the notion that large RNA molecules in the cell nucleus have a role in regulating protein synthesis. Moreover, results from recent experiments indicate that fragments from these large RNA molecules in the nucleus may be a source of messenger RNA's (mRNA's) that carry genetic information to the cytoplasm.

In the 10 years since the large RNA molecules in the nucleus were discovered, investigators have tried to determine whether some of those molecules are precursors for mRNA's. Experiments to test this hypothesis directly with radioactively labeled nuclear RNA, however, have failed to solve the problem. But investigators have been able to show that nucleotide sequences of certain mRNA's occur in the large RNA's of the nucleus. These results are consistent with, but do not prove, the hypothesis that mRNA's are derived from large nuclear RNA's.

In one group of experiments, de-