Laser Isotope Separation (LIS)

The Benefits of Laser Isotope Separation

MARK RAIZEN *

Our planet contains vast natural resources, still largely untapped. These resources hold the promise of detecting and treating cancer, saving energy, making new materials, and advancing basic science.

What are these valuable resources? Where can they be found? How can we make them available?

The answer to the first question is that the resources are *rare isotopes of the elements*. The answer to the second question is easy: these isotopes are literally in our midst, within the elements that make up our planet. The third question is the crux of the matter; isolating rare isotopes of elements has been extremely difficult because they have nearly the same physical and chemical properties as other, more common, isotopes of the same element. This is the reason that many rare isotopes are the most expensive commodity on earth, with a price that can be over one thousand times that of gold! This prohibitive cost severely limits the exploration of new applications and therapies.

Here are just two examples of rare isotopes that could be widely used if only they were less expensive : Nickel-64, a stable isotope with a natural abundance of only 1 percent. It can be converted in a medical accelerator to Copper-64 which is a short lived radio-isotope with great promise for PET scans and cancer therapy. Calcium-48 is a stable isotope with a natural abundance of 0.2 percent. It is used as a diagnostic for osteoporosis in women, bone development in children, and for a basic physics experiment that may determine the mass of the neutrino.

The only method for separating such isotopes dates back more than eighty years. This method, known as the Calutron, relies on electron ionization of atoms, and separation by the charge-to-mass ratio. Although first used in the 1930s for separating uranium, they were replaced by the gas centrifuge which is limited mostly to that element. The Calutrons remained as general purpose, though inefficient, isotope separators. Today, these machines are only operating in Russia, with an obsolete technology that is facing imminent shut-down. Without an alternative approach, most rare isotopes will not be available in the future *at any price*. The looming shortage of crucial isotopes is a national priority, as indicated by a 2009 report of the Nuclear Science Advisory Committee to the Department of Energy, "Isotopes for the Nation's Future."

I recommend this report to anyone with an interest in the scope and uses of stable and radio-isotopes. One topic discussed in this report is laser isotope separation. Although isotopes are almost identical in every manner, the wavelengths of the atomic transitions of different isotopes are slightly shifted from one another.

This "isotope shift" makes it possible to excite only one isotope with a narrow-band laser, leaving the others unaffected. The common wisdom until now has been that one must use lasers to selectively ionize the desired atoms. However, it turns out that in order to have a large probability for ionization, very high laser power at multiple colors is required. The scale is so large that it required a government effort, with one dedicated goal: laser isotope separation of uranium. This effort was ultimately terminated in 1999, mainly due to the high cost and complexity of the lasers, and to the best of my knowledge is not being pursued. Laser separation of a molecular compound of uranium is still being pursued

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* *Dr. Mark G. Raizen is the Sid W. Richardson Foundation Regents Chair and professor of physics at the University of Texas at Austin.*

The Risks of Laser Isotope Separation

FRANCIS SLAKEY *

Over the last 15 years I've criss-crossed the globe and witnessed its full range of stories. And when you see dust kick up from the bare feet of a tribeswoman walking 5 miles to get water, you realize that we face enormous global challenges, including climate change, pandemics and access to clean water, to name just a few. Regardless of our individual views on any of those issues, I'm sure that we can all agree on one thing: let's not add more challenges to the list. We have enough to deal with.

So, when the research that we carry out has the possibility of creating significant risks, then we should pause, reflect, and make sure that we don't add yet another burden to an already challenged world.

Biologists did just that – pause and reflect – in exemplary fashion a few months ago when they confronted the H5N1 issue. Concerned about potential security risks associated with publishing particular work on airborne transmission of avian flu, the relevant community of biologists put a self-imposed pause on research to consider the implications and challenges. It was thoughtfully done, with only modest reluctance from some scientists, and with benefit to all.

We are now at a moment when it would be fruitful for the relevant members of the physics and engineering communities to carry out a similar examination of the risks and benefits of some areas of isotope separation research.

So far, we've gotten lucky in uncovering when countries are developing nuclear weapons programs. However, new isotope separation technologies are emerging that are smaller, more efficient and harder, if not impossible, to detect. The technologies are in various phases of development, from basic research to commercialization. Consider this:

- Global Laser Enrichment, a joint venture of General Electric-Hitachi, is constructing and evaluating a laser-based method of uranium enrichment (SILEX) that is substantially more efficient and could leave little prospect for detection if stolen and acquired by a rogue group.

- Professor Raizen has developed a method of single-photon isotope separation using a magnetic trap and low-power laser excitation for a more efficient method to develop much-needed medical isotopes. His technique isn't intended to enrich uranium, although the potential may well be there.

These developments raise the same issue: the on-going push for greater efficiency in isotope separation carries associated proliferation risks.

These risks of more efficient isotope separation are well known to the U.S. government. For example, the SILEX technology under development in North Carolina was the subject of a multi-agency proliferation-assessment report. The report conceded that "Laser-based enrichment processes have always been of concern from the perspective of nuclear proliferation… a laser enrichment facility might be easier to build without detection and could be a more efficient producer of high enriched uranium for a nuclear weapons program."

The report ominously stated that it seemed likely that the technology would "renew interest in laser enrichment by nations with benign intent as well as by proliferants with an interest in finding an easier route to acquiring fissile material for nuclear weapons."

So the risks of enrichment technology are well

** Dr. Francis Slakey is the Upjohn Lecturer on Physics and Public Policy and the co-Director of the Program on Science in the Public Interest at Georgetown University. He is also the Associate Director of Public Affairs for the American Physical Society.*

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from a distance, and always felt there must be a solution which would be simple and cost-effective for the many smaller-scale isotopes that are needed. It came from an unexpected direction.

Over the past few years, my research has focused on developing general methods for controlling the motion of atoms in gas phase. The successful realization of these methods uses single-photons to control the magnetic state of each atom, followed by magnetic manipulation. It has brought to reality a thought experiment by James Clerk Maxwell from 1870 known as Maxwell's Demon. This work is reviewed in an article that I wrote for *Scientific American,* "Demons, Entropy, and the Quest for Absolute Zero," published in the March 2011 issue. I realized that these very same methods can also be used for efficient isotope separation with low-power solid-state lasers, a paradigm shift from ionization. We are pursuing this avenue with a proof-of-principle experiment, soon to be completed. This will then be applied commercially towards production of important medical isotopes, where the need is most urgent. In fact, this could save your life!

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Of course, the easiest path for our research community would be to claim that these risks are someone else's responsibility – we are scientists after all, not police. Yet, the biologists didn't take that easy path. They broadened their sense of responsibility outside of the lab. They paused, considered, deliberated. And there is a practical reason for doing this. If scientists don't consider the risks, we leave it to others to decide. And we may not like what they conclude.

What would we conclude from pausing and carrying out our own "stress test"? I can't predict the outcome. In the case of the biologists, they strengthened their system with a centerpiece called the National Science Advisory Board for Biosecurity that monitors "dual-use research of concern" and it has received enthusiastic endorsements from scientists. The biologists came out of the process stronger. So can we. ■