The most recent impasse in closure proceedings nearly caused a meltdown in Lithuania's relations with Brussels. In the course of the October 2004 parliamentary elections, Prime Minister Algirdas Brazauskas announced he would keep the plant's first reactor working beyond its closure deadline at the end of the year. Voters rewarded him by returning him to the country's most powerful office.

Only after the European Commission coldly reminded Brazauskas that the decommissioning was "enshrined in Lithuania's accession treaty" did the prime minister retract the statement he made weeks before.

Arturas Dainius, the state secretary at Lithuania's Economy Ministry, which is in charge of plant closure, said that "the elections didn't play the least significant role" in the government's stance. "You know," he added, "all sorts of 'interesting' ideas can pop up from the political arena."

Yet the conditions that instigated the eleventh-hour crisis over closing the first reactor will be dwarfed by the potentially catastrophic issues Lithuania will face as it prepares to close the second reactor by the end of 2008—another theoretically "enshrined" date. The energy produced by the first reactor was almost all sent abroad, but the final closure will leave Lithuania able to produce only 25 percent of its current electrical output, leaving a massive void in the country's energy supply.

With government officials admitting they have no definite plan to replace the supply from the second reactor, the hoped-for on-time closure seems doubtful. Casual proposals abound, but precious few official ideas have surfaced on how to use the aid from Brussels. "We'll either have to become an energy importer or build another plant, in which case we'll have to decide what type of plant that will be," said Dainius. Only nebulous suggestions have been discussed so far.

Lithuania's power grid has yet to be connected to the rest of the EU, meaning imported electricity would have to come from Russia—an unpopular move in a country sensitive to the giant bear's long reach. And the prospect of bringing a new nuclear reactor online in less than four years seems dim given the government's sluggish pace of decision making. "Sooner or later the reactor is going to have to close, so why don't we make sound plans for its closure now?" Jasiulionis asked.

In the meantime, even government officials do not sound confident that the second reactor will be closed. "We'll live, and we'll see," Dainius told me.

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LASER ENRICHMENT

Separation anxiety

By Jack Boureston & Charles D. Ferguson

On November 2004, the environmental group Greenpeace accused the Australian government of condoning nuclear proliferation by supporting the work of a laser uranium enrichment company named Silex Systems Limited. "If any other country, be it Iran, Syria, or Iraq was involved in this research it would be taken as a sign of a covert weapons program," a Greenpeace spokesperson told reporters.

Nations have been developing laser isotope separation methods to enrich uranium for years, but most have yet to convert research into commercial success or have abandoned laser enrichment altogether. The recent accusations and the diffusion of laser enrichment technologies and know-how as part of peaceful nuclear programs nonetheless again raise the question: How much of a proliferation risk does laser isotope separation present?

Analysts have paid relatively less serious attention to the use of laser isotope separation (LIS) to enrich uranium than to the spread of gas centrifuge enrichment and reprocessing technology. But certain features of laser enrichment facilities would seem to make them ripe for proliferation—they are typically smaller, use less energy, are more easily concealed, and may one day be cheaper to operate than both gas centrifuge and diffusion plants. Still, there are formidable obstacles to their development.

Some analysts have regarded laser isotope separation as too difficult to master by nations lacking highly advanced technical infrastructures.

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One exception is Stanley Erickson, an analyst at Lawrence Livermore National Laboratory. In an October 2001 paper Erickson warned, "As technology advances, this will not remain so." This observation proved prophetic in August 2002, when the dissident group National Council of Resistance of Iran announced at a Washington, D.C., press conference that Iran had started an LIS program and developed a laser enrichment facility at Lashkar Ab'ad.

The Iranian laser research program, which enriched only milligrams of uranium, had surprisingly managed to escape detection by the International Atomic Energy Agency (IAEA). In February 2003, IAEA Director General Mohamed ElBaradei acknowledged that the IAEA would continue having problems detecting similar "research and laboratory activities" in the future. But ElBaradei hastened to add that the IAEA's improved technological capabilities would make it "highly unlikely" that an industrial-scale LIS program would go undetected.

Is laser enrichment a proliferation risk? Greenpeace says "yes" at this September 2003 protest in Australia.

AFP

Another hidden research effort using laser enrichment came to light in September 2004, when the IAEA exposed South Korean experiments (for more on this, see "South Korea's Nuclear Surprise," January/February 2005 *Bulletin*). In 2000, scientists at the Laboratory for Quantum Optics at the Korea Atomic Energy Research Institute (KAERI) separated about 0.2 grams of uranium 235, an isotope useful in nuclear fuel or weapons, and enriched them to levels between 10 and 77 percent. While 20 percent is the dividing line between low-enriched and highly enriched uranium, enrichment levels close to 90 percent are sought for the purposes of making weapons. Sufficient amounts of uranium enriched to 77 percent could fuel a nuclear bomb.

Scientists need tens of kilograms of enriched uranium, more than 100,000 times the amount enriched, to make a weapon, and analysts drew clear conclusions about Seoul's intentions. "If the question is, could KAERI have enriched a significant amount of uranium using the facility they had in that laboratory, I'm highly confident the answer is no," Jeffrey Eerkens, a leading American laser enrichment expert, told *Nucleonics Week* (September 9, 2004). Yet, scientists wouldn't need a commercial-scale LIS plant to enrich enough uranium for a single nuclear weapon if they had one or two years to do so.

This is perhaps why South Korea's laser enrichment activities were of some concern to the U.S. government. In November 2001, Eerkens gave a presentation on laser isotope separation techniques at a scientific conference in South Korea. The next year, he proposed to the Energy Department that he work with a KAERI scientist to investigate laser separation of zinc isotopes and other isotopes useful in medical applications. Energy denied the proposal "because it was too close to uranium enrichment," Eerkens told *Nucleonics Week* and confirmed for us.

Although the IAEA has reprimanded South Korea for not reporting its uranium enrichment activities in a timely fashion as required by its Safeguards Agreement, the United States has not expressed serious concern. In early November 2004, before the IAEA Board of Governors meeting, Secretary of State Colin Powell said, "I'm quite sure that the IAEA will see it as a minor problem with experimentation."

How it works

For more than 30 years, enthusiasts have trumpeted the benefits of laser enrichment of uranium. The energy costs are much lower than traditional enrichment techniques; lasers can, in principle, target uranium 235, the isotope useful for fuel and bombs, while leaving uranium 238, the most prevalent isotope, alone. But because the two isotopes have very similar excitation frequencies, the laser beams used to selectively excite uranium 235 must be finely tuned and have a narrow frequency spread, which is technically demanding to achieve.

Scientists have investigated two types of laser enrichment techniques: atomic vapor laser isotope separation (AVLIS) and molecular laser isotope separation (MLIS). In AVLIS, tunable dye lasers target vaporized uranium metal and selectively excite and charge uranium 235. (Copper vapor lasers are typically used to pump the dye lasers.) The positively charged uranium 235 collects on negatively charged plates and is then extracted in a labor-intensive process. In principle, a single-stage AVLIS plant could make low-enriched uranium suitable for reactor fuel, and a three-stage plant could produce about one bomb's worth (25 kilograms) of weapon-grade uranium per year. Inadvertently charging and collecting uranium 238 is a major problem with this technique.

The AVLIS setup at Lawrence Livermore National Laboratory.

LAWRENCE LIVERMORE NATIONAL LABORATORY

In MLIS, an infrared laser is directed at uranium hexafluoride gas. The laser excites uranium 235 hexafluoride gas, while not disturbing the uranium 238 hexafluoride gas. Another laser knocks a fluorine atom off an excited uranium 235 hexafluoride molecule, creating uranium pentafluoride, which precipitates out as a white powder and contains enriched uranium. Because producing even low-enriched uranium for commercial purposes is very difficult for a single-stage MLIS plant, cascading is necessary. Each stage in the cascade requires refluorination of the uranium pentafluoride, a process that can substantially increase the costs of MLIS when compared to AVLIS.

Jack Boureston & Charles D. Ferguson

South Korea and Iran were neither the first nor the last to experiment with laser enrichment. In fact, more than 20 other countries have researched laser isotope separation techniques. They include Argentina, Australia, Brazil, Britain, China, France, Germany, India, Iraq, Israel, Italy, Japan, the Netherlands, Pakistan, Romania, Russia, South Africa, Spain, Sweden, Switzerland, the United States, and Yugoslavia.

Most of these nations have confined their LIS work to the laboratory. Britain, France, and the United States have developed LIS programs that could move beyond the lab into the pre-industrial phase and ultimately into commercial production. Australia and Japan are also known to have invested significant resources in trying to build LIS uranium enrichment plants, but no country currently operates a commercial-scale laser enrichment facility for separating uranium, according to the Uranium Information Centre in Australia.

AVLIS has left the building

The United States was on the verge of commercialization, when USEC, then known as the U.S. Enrichment Corporation, decided in June 1999 to cancel its atomic vapor laser isotope separation (AVLIS) program. This came as a surprise considering USEC had spent roughly $100 million on AVLIS since being privatized a year earlier. In total, the U.S. AVLIS program involved 27 years of research and development and an investment of some $2 billion. USEC's cost estimates to make AVLIS ready for commercialization, which soared into the hundreds of millions of dollars, were a major factor in the program's cancellation.

U.S. interest in laser enrichment methods did not immediately die with the AVLIS program. In 1996, USEC had invested in the separation of isotopes by the laser excitation (SILEX) technique being developed in Australia. The U.S. and Australian governments demonstrated further interest in the project on June 20, 2001, when they announced that they had officially classified the SILEX method. But USEC's interest in SILEX proved short-lived, and on April 30, 2003 it terminated SILEX funding.

In a May 1, 2003 press release, Michael Goldsworthy, chief executive officer of Silex Systems, said that his company disagreed with USEC's view of the potential and current state of the SILEX technology. "It is incomprehensible to us that USEC has decided to abandon the SILEX program only a few months short of completing the current test program and being in a good position to assess the economic performance of the SILEX process," he said. As of July 2004, Silex Systems was still studying the economic feasibility of its laser uranium enrichment method.

After abandoning laser isotope separation methods altogether, USEC is now focusing on plans to build a centrifuge plant in Piketon, Ohio, the site of the former Portsmouth Gaseous Diffusion Plant. In 2005, USEC hopes to begin operating the American Centrifuge Demonstration Facility at the site, and by 2010, the company wants to construct the most efficient centrifuge plant in the world with an annual capacity of 3.5 million separative work units of enrichment. This plant could provide enough fuel yearly for between 30 and 35 1,000-megawatt light-water reactors.

Gas centrifuge and diffusion methods continue to dominate the global nuclear fuel enrichment market. By choosing to build a centrifuge enrichment plant, USEC went with a proven commercial method, reducing financial risks. Although a centrifuge facility requires more energy to run than a laser enrichment plant, it will save substantially compared to USEC's remaining gaseous diffusion plant in Paducah, Kentucky, which is approaching the end of its life.

Laser allure

The potential of LIS has attracted states eager to establish a domestic enrichment capability. Like the United States, Brazil invested in a laser enrichment program for many years but eventually chose to build a commercial centrifuge plant. Brazil's laser project aimed to "demonstrate the technical viability of the laser processes for isotope separation using, as long as possible, resources available in Brazil," according to a 1998 scientific article by a research team centered at the Instituto de Estudos Avançados. That report cautioned, "A successful commercialization of this technology will threaten well-established fuel-cycle activities."

Brazilian laser research planning originated in the United States in the early 1970s, and was led by Sergio Porto, a Brazilian scientist and professor at the California Institute of Technology and the University of Southern California who took a special interest in educating Brazilian students. Porto returned to Brazil in 1975 to head its laser enrichment program, which was controlled by the air force and supported by the National Nuclear Energy Commission.

The Brazilian program has had mixed results. Brazilian researchers we contacted declined to release details of how much uranium they have enriched and to what level of enrichment, but Eerkens, the laser enrichment expert, told us that he believes they probably attained a level of 50 percent enrichment. Uncertainty remains about the total amount of uranium enriched. And the program has struggled with extraction and separation of the enriched uranium.

Brazilian scientists take pride in both their laser and centrifuge accomplishments, and Brazilian resistance to allowing IAEA inspectors full access to the centrifuge facility made headlines in September and October 2004. Eduardo Campos, Brazil's minister of science and technology, has claimed that the centrifuge technology at the facility is "100 percent" Brazilian. Outside experts doubt this claim, yet broadening domestic enrichment capabilities, in Brazil and elsewhere, present some concern.

Faced with stiff competition from gas centrifuge facilities, laser enrichment programs may never see large-scale commercialization. But LIS might offer a clandestine means for producing a few bombs' worth of weapon-grade uranium. According to Stanley Erickson's paper, "the requirements for a proliferation facility using LIS are not as strenuous as they are for commercial production of nuclear fuel."

During the past few decades, the materials and know-how necessary to build laser systems useful for uranium enrichment have spread widely. For instance, copper vapor laser systems, once costly and technically prohibitive, are now built by high school students for science projects and employed in undergraduate laser laboratory experiments. Dye lasers, another essential component of AVLIS enrichment, are also becoming more available. "This diffusion of laser knowledge and experimental interest means that expertise about the finer points of laser construction is spreading and will make development of [lasers] easier," observed Erickson.

LIS facilities could escape detection more easily than traditional uranium enrichment plants. They would be more compact than a centrifuge plant with an equivalent capacity, and a lot of LIS research has taken place at universities, which are typically not safeguarded facilities. Moreover, the lasers used in LIS have several dual-use applications. This was one of the concerns raised about Silex Systems' operations in Australia. In response to the November Greenpeace report, Australia's defense minister, Robert Hill, acknowledged that dual-use materials from Australia might have been "innocently" exported and used within an unnamed country's nuclear weapons program.

Another worry is that a nation can hone its LIS skills with elements other than uranium, while developing a breakout capability and minimizing the potential triggering of safeguards. To enrich other elements requires the same LIS equipment used to enrich uranium, only tuned to different laser frequencies. One such element is ytterbium, which has few industrial applications. "If they knew how to enrich ytterbium, then they could enrich uranium," according to Eerkens.

Export controls

Nonproliferation analysts have debated whether current export controls could better address the risk of LIS proliferation. At a 1999 science and security conference at Fudan University in Shanghai, David Daniels, then a Harvard graduate student in physics, concluded, "The current international system is able to safeguard a declared LIS facility, but it is not able to timely detect the diversion of significant amounts of uranium to a LIS facility." However, this international system "may prevent the construction of new plants through appropriate export controls." In contrast, Erickson's paper warned that advanced technologies could "outflank" export controls in "nations with moderate-size economies during the first decades of the twenty-first century."

To combat these possibilities, Erickson recommends creating a comprehensive map of proliferation that would require "more labor-intensive" research on the "training, work experience, and scientific interchange of nationals of a possible proliferating nation." The map would also identify the "list of technical achievements" required for each LIS method and "what scientific knowledge or engineering know-how is needed for each." Daniels has encouraged a reexamination of the ability of export controls to catch clandestine operation of LIS plants.

Any steps to prevent the spread of LIS technologies would require a greater technical understanding than is used in establishing conventional export controls. First, officials should determine what aspects of LIS can mask as civilian research and assess where such research is taking or may take place. While the IAEA's Additional Protocol requires nations to declare LIS facilities, identifying the nascent phases of LIS research that could eventually be applied to uranium enrichment presents another challenge.

The nonproliferation regime also should guard against an A. Q. Khan-like theft of LIS uranium enrichment technology. In the 1970s while working for the uranium enrichment consortium URENCO, Khan, a Pakistani metallurgist, stole designs for uranium centrifuges. He used this purloined knowledge to build Pakistan's centrifuge enrichment plants, which supplied the highly enriched uranium for Pakistan's nuclear weapons. He also distributed the designs and centrifuge components through a nuclear black market. Today, using LIS for bomb-scale uranium enrichment appears out of potential proliferators' reach, but the further spread of LIS expertise and technologies increases the risk that someday another Khan will peddle these tools to the highest bidder.

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IDAHO

Nuclear comes home to roost

By Jonas Siegel

SINCE 1949, THE ENERGY Department, other federal agencies, and the navy have built and tested 52 nuclear research reactors in the high desert plains of southeastern Idaho; a few still operate today. Number 53 might be built at the new Idaho National Laboratory (INL), if the Energy Department has its way.

INL, formed on February 1, is a consolidation of the Idaho National Engineering and Environmental Laboratory (INEEL) and Argonne National Laboratory–West. "Our goal, within this decade, is to have this lab emerge as one of the premier applied research and nuclear engineering institutions in the world," then-Energy Secretary Spencer Abraham said in April 2003.

The renewed emphasis on nuclear energy research is one aspect of Energy's expanding Idaho operations. The laboratory will also continue playing a greater role in homeland security-related research, and may eventually house all of Energy's work on plutonium-decay power generators for spacecraft, including a new plutonium 238 processing facility. But INL faces doubts about its new missions, as well as questions and criticisms from Idahoans.

Investing in nuclear energy

In 2002, the United States and 10 other members of the Generation IV