# Focusing on Iran's Laser Enrichment Program

By Charles D. Ferguson and Jack Bourestton

**FirstWatch International**

June 17, 2004

## Introduction

Analysts have suspected for decades that Iran was experimenting with laser isotope separation (LIS) processes to enrich uranium. However, confirmation of Iran's use of LIS did not occur until August 2003, when the IAEA visited the laser laboratory at Lashkar Ab'ad. The IAEA was investigating information about enrichment facilities at Natanz and Lashkar Ab'ad provided by the dissident group the National Council of Resistance of Iran (NCRI), which held press conferences on 14 August 2002 and 20 and 21 February 2003.

During the visit, Iranian authorities described the laboratory as originally having been devoted to laser fusion research and laser spectroscopy. However, they indicated that the focus of the laboratory had been changed and equipment unrelated to the site's current projects, including a large vacuum vessel imported in 2002, had been moved, according to the IAEA's report of 10 November 2003. In a letter dated 19 August 2003, as a follow up to the IAEA's visit, the Iranian authorities acknowledged that they had a research and development programme on lasers, but they did not presently have an active LIS programme.

The IAEA made another visit on 2 and 3 October 2003 in which its experts were allowed to take environmental samples at Lashkar Ab'ad. This visit led to an Iranian letter, dated 21 October 2003, to the IAEA disclosing past contracts to perform LIS studies. This declaration provided insights into

Iran's attempts to establish facilities and described some of the imported LIS-related equipment. While this new information supported the West's suspicions and NCRI's claims, the full extent of Iran's research and development with LIS remains unknown despite further revelations and clarifications stemming from the April/May 2004 visits by IAEA experts to Iran. As with Iran's work on uranium centrifuge technology, successful application of laser enrichment could give Iran a means to produce commercial low-enriched reactor fuel or weapons-grade highly enriched uranium.

**Chronology of Iran's LIS programme**

According to Iran's declaration, they began experimenting with LIS in the 1970s. In 1974, the Laser Physics Group was formed to begin limited laser research activities, according to a 1993 report from the Tehran news service *Ettela'at*. During that time, both atomic vapour laser isotope separation (AVLIS) and molecular laser isotope separation (MLIS) techniques were investigated (see box for a description of each method).

In 1975, Iran contracted with a supplier to establish a laboratory to investigate the spectroscopic behaviour of uranium metal at the Tehran Nuclear Research Centre (TNRC). At that time, the laboratory may have been called the Research Centre for Lasers & their Applications (RCLA) but it may have finally evolved into the Laser Research Centre (LRC). According to the letter of 21 October 2003, although the laboratory was constructed, the programme work done there was halted in the 1980s because the laboratory was not functioning properly. In 1976, Iran had purchased two mass spectrometers, which were used much later in the laboratory to analyse samples of nuclear material obtained from enrichment experiments.

In the late 1970s, Iran contracted with a supplier to study MLIS, under which four 5µm carbon monoxide lasers and four vacuum chambers were delivered. Although the supplier was not specified in the IAEA's November 2003 report, this import coincides with other reports that in 1976, Dr Jeffrey Eerkens, a scientist who worked on the US uranium enrichment programme, travelled to Iran. In the subsequent year, he met with Dr. Mojtaba Taherzadeh, then head of the TNRC, and according to the *Los Angeles Times*, Taherzadeh agreed to provide financing for Eerkens' newly formed company Lischem.

As described in Leonard S Spector's 1987 book *Going Nuclear*, Iranian officials also decided to purchase four experimental lasers from Eerkens (they initially considered buying six lasers). Eerkens claimed at that time that the four-laser system could produce about a kilogram of five per cent enriched uranium per day. It is difficult to extrapolate to how much weapons-grade highly enriched uranium could be produced with such a system. However, according to the estimate in *Going Nuclear*, this system might allow production of approximately 25kg of weapons-grade uranium in five months – enough for one nuclear bomb – but this is highly uncertain. Lischem reportedly shipped four lasers to Iran in October 1978, just a few months before the overthrow of the Shah.

The Eerkens' laser system was reportedly capable of producing 16µm light – ideal for the enrichment of uranium with the MLIS technique – but was modified to produce only 5µm to fit export restrictions, according to *Going Nuclear*. (As discussed in the box, carbon dioxide lasers actually produce 10.6µm light, which is shifted to the desired MLIS wavelength of 16µm.) Notwithstanding export control constraints, the lasers could be changed back to their original light-producing capacity by changing the gas within the lasers – a fact that Eerkens told the *Los Angeles Times*. (In addition, some of the laser optics, which is usually coated for specific wavelength ranges, would probably also have to be changed.) He reportedly believed that Iran was only interested in making low-enriched fuel for reactors.

No further contact between Eerkens and Iranian officials has been reported. Co-operation may have been halted or at least postponed due to the Iranian hostage crisis and subsequent political upheaval of the Iranian government in 1979. During the early 1980s, the new government was uninterested in nuclear technology most probably because of Ayatollah Khomeini's opposition to Western influences, and consequently, the pace of advancement in nuclear technology in Iran slowed.

In the late 1980s, Iran began a new phase of development in laser research. During a conference held in 1987, evidence emerged that China had provided laser systems to Iran to further Iranian LIS research, as reported in the June 1995 issue of *JIR*. According to the *Ettela'at*, Iran formally re-established the LRC in 1989. It was during this time that Iranian technicians could have operated and re-engineered the lasers provided by Eerkens, and possibly the Chinese, to develop their own indigenous systems.

In 1991, Iran contracted with an unknown supplier to establish a laser laboratory, which contained two research facilities: the Laser Spectroscopy Laboratory (LSL) for the spectroscopic study of uranium metal and the Comprehensive Separation Laboratory (CSL) for study of uranium enrichment at the milligram scale, according to the November IAEA report. These labs were located at the TNRC. Based on a 1993 *Ettela'at* interview with then deputy head of the Laser Research Centre, Fereydun Soltan-Moradi, the LSL and CSL were integral parts of the LRC, which consisted of several research and training facilities devoted to laser activities applicable to medical and industrial purposes as well as LIS. However, the published interview with Soltan-Moradi does not specifically mention uranium enrichment. Once established, LRC activities were divided into three separate functional sections, namely research, production, and support.

The research section investigated LIS technologies and implementation of the LRC's stated goals to carry out research in the medical, optical, and agricultural fields. The research section comprised the carbon dioxide gas laser laboratory, the nitrogen laser laboratory, the solid-state laser laboratory, the precision laser laboratory, the laboratory for polymer lasers, a series of semi-guided laser laboratories, and holography laboratories that were used for three-dimensional photography. According to the Atomic Energy Organisation of Iran (AEOI) website, the research section examines high-power carbon dioxide medical lasers, dye pumping with various lasers, and copper vapour lasers for medical applications. Notably, all three of these technologies are applicable to LIS.

The production section consisted of at least one major line to produce both helium-neon lasers and carbon dioxide lasers. The latter can be useful for the MLIS technique. Located at the LRC and working under direction of the production section are units that have manufactured glass parts for lasers, optical laser equipment, as well as mirrors, filters, and other components that are necessary for producing lasers. An electronic unit to manufacture electronic components and a technical unit were also operated to provide the mechanical-optical components for lasers. Soltan-Moradi commented that the production section was able to make all the components for some lasers but for others they still required components from outside suppliers.

However, for one type of laser relevant for AVLIS, Iran apparently has an indigenous capability. As early as 1998, Iran's LRC was "producing indigenous neodyne [neodymium] ytterbium-aluminium (Nd:YAG) lasers, using laser crystals which are also now produced in Iran. The Iranian pulsed lasers can be operated at double frequency at a wavelength of 532 millimicrons [0.532µm] in the blue-green spectrum," as reported in a 5 October 1998 *Nuclear Fuel* report on LIS experiments in several countries. Frequency doubling is useful for AVLIS because it produces a laser beam that can pump dye lasers applicable to AVLIS systems. The AEOI itself stated on its website, which was updated in 2002, that the LRC produces Nd: YAG lasers with second, third, and fourth harmonics, and pumped solid-state lasers. More recently, the 1 June 2004 IAEA report notes that the LRC is continuing its work on (250ns) Nd:YAG lasers, "which could be useful in Iran's AVLIS programme if the pulse width is shortened".

The support section at the LRC assisted the research and production sections in their work. For instance, the support section helped the glass tube manufacturing unit in its endeavours to produce tubes and other glass parts.

In 1993, the supplier that helped establish both the LSL and CSL also provided Iran with 50kg of natural uranium metal. Based on the best available information from the IAEA reports to date, Iran conducted at least two sets of experiments with this uranium. The first round at TNRC involved 8kg. It has not been reported exactly when this experimentation took place but the June 2004 IAEA report implies some time during the 1990s. The second set of experiments employed 22kg of the uranium metal and occurred from October 2002 to January 2003 at the Lashkar Ab'ad facility. It is not known if Iran experimented with the remaining 20kg or may have placed it at the radioactive waste storage facility in Karaj along with the other quantities of uranium metal.

The equipment at CSL was capable of enriching uranium on a milligram scale up to the three per cent uranium-235 (U-235) goal for low-enriched reactor fuel (three per cent enrichment) and "even slightly beyond," as reported in

November 2003 by the IAEA. Although the June 2004 report confirmed the production capacity of “a few milligrams of uranium a day” at CSL, the IAEA revealed that Iran was able to achieve greater enrichment levels than previously stated by Iranian officials. The average levels were eight to nine per cent and some samples were as high as approximately 15 per cent. However, even in kilogram amounts, 15 per cent enriched uranium would not be practicable for a nuclear weapon. On 21 May 2004, Iranian officials told IAEA experts that “the higher enrichments arose from initial tuning experiments of the AVLIS equipment and that it was not possible for the experimenters to know or control in advance the range of enrichment of all the material.” The June report noted that the IAEA is investigating this explanation.
Iran stated in its 2003 correspondence with the IAEA that activities continued at CSL and LSL until October 2002, when the laboratories and nuclear material were moved from TNRC to Lashkar Ab’ad. The second group of experiments took place at Lashkar Ab’ad, where the production capacity was substantially greater than at CSL. IAEA experts determined during the April and May 2004 missions to Iran that the capacity “was about one gram of uranium per hour but that continuous operation was not possible”. Even assuming continuous operation and the theoretical capability of producing highly enriched uranium (HEU), this facility would not have been able to produce one bomb’s worth of HEU per year.

In 1998, Iran contracted with a supplier to obtain information related to laser enrichment and related equipment. Only a portion of that equipment was imported and delivered to Lashkar Ab’ad due to the exporter’s difficulty in obtaining an export license. However, as was stated in the IAEA’s November 2003 report, the equipment that was imported from 1992 to 1999 was sufficient for constructing and operating a pilot-scale AVLIS uranium enrichment plant. This corroborates previous unclassified reports from the

US Central Intelligence Agency (CIA) and the German foreign intelligence agency (Bundesnachrichtendienst - BND) stating that AEOI was working on AVLIS methods as well as MLIS.

In 2000, Iran constructed an AVLIS uranium enrichment pilot plant at Lashkar Ab'ad. That facility contained some of the equipment originally contracted for use with the Lashkar Abad supplier, LIS-related equipment that was transferred from the LSL, CSL facilities, and a number of copper vapour lasers (CVL) that were obtained from an unknown source. That source is probably Russia, as discussed below. However, China was also reportedly active in the mid-1990s in providing CVL technology to Iran. What is known is that in 1994, China transferred at least one CVL to the Ibn-e Heysam Research and Laboratory Complex at the TNRC, according to Mark Hibbs in the 14 March 1994 issue of *Nuclear Fuel*.

In 1999 or 2000, Iran approached Russia to acquire additional laser technology. According to a 20 September 2000 report in the *New York Times*, the D V Efremov Institute in Russia attempted to provide Iran with a CVL with an average power output of 15 to 20W. CVLs can be used in the AVLIS method of uranium enrichment. However, despite the fact that the export control threshold for a CVL is 40W, US pressure on Russia halted the deal on 21 September 2000. CVLs for AVLIS systems usually are much more powerful, and 15 to 20W CVLs are typically used in industrial or research applications, such as micromachining. A US official (interviewed by Mark Hibbs for the 20 January 2003 edition of *Nuclear Fuel)* specified that Iran needs items that would enable it "to squeeze all the laser power onto a narrow line width with a precise repetition rate".

Iranian researchers conducted LIS experiments at Lashkar Ab'ad from October 2002 to January 2003, as discussed above. Iran indicated to the

IAEA that LIS-related equipment at this site was dismantled in May 2003 and transferred to Karaj. As stated in its June 2004 report, the IAEA continues to investigate the extent of Iran's LIS activities.

**Estimate of current Iranian LIS capabilities**

It is difficult to determine Iran's LIS capability for a number of reasons. First, although the reported level of success – milligram quantities - to enrich uranium at LSL and CSL at the LRC is far below the kilogram amounts needed for nuclear fuel or weapons, there still is a question as to the success of the experiments that were conducted at the pilot plant at Lashkar Ab'ad between October 2002 and January 2003.

Second, Iranian officials do not appear to have provided a full history of Iran's LIS programme. According to Iran's 2003 declarations, it appears that all the lasers that were used in experiments have been dismantled and placed in storage. Still unknown are the number of lasers that were produced from the various phases of operation of the LRC and their exact locations. It is worth noting that having the proper lasers is not sufficient for a functioning LIS programme. For instance, Iranian scientists and engineers would have to master other technologies, such as electronic-beam guns, vacuum vessels, and control systems. The extent of this activity is also unknown.

However, raising suspicions about continuing laser research, the IAEA's June report states that Iran is continuing research and development on CVLs, and as previously mentioned, the Agency discovered in May 2004 that the LRC is working on Nd:YAG lasers. Both technologies could be useful for AVLIS.

Concerning Iran's current LIS capability, three possible scenarios should be considered. Scenario number one would be that the Iranians, as they declared to the IAEA, have disassembled all lasers that have been used in or are readily capable of LIS operations and packed them away to be verified by the IAEA. In this case, there is a latent but not a current LIS capability in Iran. However, this scenario appears unlikely in light of the continuing work on copper vapour and Nd: YAG lasers, which might be adapted to LIS.

The second scenario would involve deception. In that case, Iranian officials may have presented to the IAEA a portion or sample of those lasers and equipment, which they knew would be of interest to the international community. This hypothetical partial revelation may satisfy the IAEA's curiosity regarding Iran's LIS programme. The other portion of the programme may have been hidden away with a quantity of uranium metal to be used at a later date to continue LIS experiments.

The third scenario is a variant of the second. It involves continued LIS operations even as we write which means that the Iranians could be enriching uranium using LIS even today. As noted in the box, LIS facilities take up very little room and tend to be significantly smaller than centrifuge enrichment plants. However, this scenario only suggests a continued capability but does not provide a quantitative assessment of how much enriched uranium Iran can produce using LIS methods.

In addition to laser technology and equipment, Iran has developed and maintained a scientific intellectual base that understands LIS technologies. Training in this field may have begun in the 1970s when Eerkens first visited and discussed the transfer of LIS technologies and equipment. Since then, the LRC has trained numerous scientists in the technology. In a 1993 interview, LRC deputy head Fereydun Soltan-Moradi said the centre had "undertaken to expand this technology to a national level. So far it has been able to train a large number of experts". The LRC works closely with educational institutions across the country to groom the next generation of laser scientists and technicians. According to Soltan-Moradi, for example, Iranian youths who showed interest in the field have been encouraged to take a course called advanced laser technology. The previously mentioned German BND report also describes co-operation between the LRC and higher educational institutions. It states that “the LRC is co-operating in laser enrichment research with the Jihad-e Daneshgahi Department of the Sharif University in Tehran”.

LRC’s experts have also been involved in co-operative projects, seminars, and other scientific gatherings to increase their knowledge. For example, the LRC has maintained close ties from earlier phase of development with the Trieste Centre in Italy. Groups of Iranian scientists from the LRC have visited Trieste to participate in courses, lasting one month or longer, according to

Mark Hibbs in the 20 January 2003 issue of *Nuclear Fuel*. Moreover, South Africa sent advisors to Iran, as reported by Ian Hoffman in the 12 November 2003 edition of the *Tri-Valley Herald*. That report notes that in 1991 and 1998 Iran contracted with South Africa for laser assistance.

**LIS and centrifuge enrichment interaction**

It is still too early to have the complete picture regarding Iran’s LIS programme. However, enough information is available to demonstrate that Iran established a LIS pilot plant and operated it for a period of time before disassembling it. Iran also has studied both the MLIS and AVLIS enrichment methods, and the reported experiments on uranium metal used the AVLIS technique.

How did Iran’s LIS work interact with its centrifuge enrichment activities? In

January 2003, *Nuclear Fuel* reported that, “the record of procurement efforts by Iran during the 1990s and until quite recently suggests that Iran has been trying to find technical shortcuts to overcome difficulties experienced in centrifuge development and manufacture”. However, one might argue that LIS was the first method that Iran attempted to enrich uranium. Starting in the 1970s, with the help of an US scientist, Iran learned about LIS technologies and purchased a number of lasers. As procurement paths closed and opened up, Iran may have experimented with multiple enrichment technologies, ultimately opting for centrifuges because of their co-operation with Pakistan’s A Q Khan and his Khan Research Laboratory network and the proven track record of this technology.

That said, Iran may have perfected its LIS programme sufficiently to manufacture lasers and use them to enrich small amounts of uranium. However, this is not enough to have the capability to produce kilogram quantities of enriched uranium. To reach this level, Iran would have to develop an enrichment plant that integrates the Iranian research and development on LIS with control systems capable of operating a facility that could run over a long period of time. As noted above, Iran had not apparently achieved “continuous operation” of the Lashkar Ab’ad pilot enrichment facility. Thus, Iran’s development of LIS uranium enrichment may have been the backup plan in the event that the centrifuge effort did not succeed.

**Appendix: AVLIS and MLIS Methods**

Two main laser isotope separation methods have been developed: atomic vapour laser isotope separation (AVLIS) and molecular laser isotope separation (MLIS). As the names imply, the primary difference between the two techniques is that AVLIS involves uranium in its atomic state, in other words not chemically attached to other elements, while MLIS operates on uranium that is chemically combined with fluorine to produce the chemical compound uranium hexafluoride. Each process also uses different types of lasers. However, both techniques target uranium-235 – the isotope useful for fuel and bombs – in order to separate it from uranium-238.

In the AVLIS method, uranium metal is vaporised to create a gaseous mixture of uranium-235 and uranium-238 atoms. Powerful pulsed lasers operating in the green-yellow part of the visible spectrum (copper vapour lasers or, more recently, frequency-doubled diode-pumped Nd:YAG lasers) excite tunable dye lasers, which are tuned to specific wavelengths in the red-orange part of the visible spectrum optimised to selectively excite and photoionize uranium-235. The positively charged uranium-235 ions are attracted to and collected on negatively charged plates.

In the MLIS process, a 16µm infrared laser beam is shined on an expansion-cooled gaseous mixture of uranium hexafluoride (containing both uranium-235 and uranium-238 isotopes combined with fluorine) and an inert carrier gas, such as argon or nitrogen. High-pressure pulsed carbon dioxide lasers can be employed to produce a 10.6µm beam, which then can be Raman shifted to produce the 16µm beam, which is precisely tuned to excite only the uranium-235 hexafluoride. Another laser beam, either from an infrared or ultraviolet laser, is directed on this excited molecule to dissociate it into fluorine gas and uranium pentafluoride, a white powder, which precipitates out from the gaseous mixture. The uranium-235 pentafluoride is then re-fluorinated to produce uranium hexafluoride. A variant of this method is chemical reaction by isotope-selective laser activation (CRISLA) in which energetically excited uranium-235 hexafluoride preferentially reacts with a proprietary reagent. The product of this reaction can then be separated from the gaseous mixture by standard chemical techniques.

Both processes offer advantages. First, the building housing the LIS system would be smaller than that needed for a centrifuge enrichment plant of comparable output. Second, the energy costs for a LIS plant would also typically be less than the energy expended in a centrifuge facility. Third, lasers can be tuned to be highly selective for the isotope of choice: uranium-235.

However, some substantial disadvantages could block many states from developing LIS systems. First, obtaining parts, such as the appropriate lasers, could be very challenging and making all these components work in an integrated manner could also be very difficult. Second, the technology of LIS does not have the proven track record of prolonged reliable usage that the centrifuge method offers. Third, there can be significant material losses in a LIS system. For instance, recovering the uranium-235 in an AVLIS system after each production run can be difficult. Also, not all of the uranium-235 will be ionised and, therefore, collected. Some uranium-238 will be inadvertently ionised and will then be collected along with the uranium-235, requiring further passes through the LIS system to achieve high enrichment levels, if so desired.

*Charles D Ferguson is the science and technology fellow at the Council on Foreign Relations.*
*Jack Boureston is Managing Director and senior research analyst at FirstWatch International (FWI), a private WMD proliferation research group in Monterey, California (http://www. firstwatchint.org). He has worked as a safeguards information analyst at the IAEA and researcher at CNS.*