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Lashkar Ab'ad: Iran's Unexplained Laser Enrichment Capabilities

David Albright and Serena Kelleher-Vergantini

Summary

Iran has taken many actions that have compounded suspicions that it has not stopped its uranium laser enrichment activities. They include Iran's development of advanced lasers suitable for uranium enrichment, its past secret laser enrichment program, the extensive construction at the site of its original undeclared uranium laser enrichment program (Lashkar Ab'ad), and a 2010 high-profile Iranian announcement about having a uranium laser enrichment capability. As a result, although concerns about Iran's centrifuge and heavy water reactor programs are more pressing, the International Atomic Energy Agency (IAEA) is justified to also pursue whether Iran has had undeclared uranium laser enrichment activities since 2003. Iran has so far not provided the IAEA with the necessary information and access to resolve these concerns.

This ISIS report uses commercial satellite imagery to show the substantial growth of the Lashkar Ab'ad site, where Iran conducted secret laser enrichment activities into 2003. This report reviews Iranian scientific journal articles, and compares authors, their organizational affiliations, the addresses of such affiliations, and the evolution of these affiliations, concluding that Iran has developed advanced lasers that are suitable for use in laser enrichment of uranium, and that Lashkar Ab'ad is at the center of this work. In addition, Iran has taken steps to hide the linkage of Lashkar Ab'ad to these organizations, one of which has been sanctioned by the United States and the European Union allegedly for work on laser enrichment of uranium.

As long as Iran does not satisfy the IAEA's concerns, additional measures are recommended that increase Iran's difficulty to pursue laser uranium enrichment programs. They include additional sanctions designations for specific organizations and individuals. In addition, countries should make a higher priority of detecting and thwarting any Iranian procurements of laser enrichment related technology, equipment, and materials, including subcomponents of advanced lasers.

Questions about Iran's laser enrichment activities reinforce the need for it to ratify the Additional Protocol and accept additional verification measures as soon as possible to ensure that Iran, a known multiple violator of its safeguards agreements, is not pursuing secret, undeclared nuclear activities.

A Secret Past

Iran is one of three non-nuclear weapon states, the others being Iraq and South Korea, that have operated small, secret laser uranium enrichment programs in violation of their safeguards agreements, according to the International Atomic Energy Agency (IAEA).¹ Iran and South Korea produced small amounts of enriched uranium. The Iranian program was the most successful of the three when it was exposed by the IAEA in 2003 and 2004. While none of the programs found it feasible to produce kilogram quantities of highly enriched uranium (HEU), all three countries were able to make strides in laser enrichment while avoiding detection.

The centerpiece of Iran's past laser enrichment work was a site located near the town of Lashkar Ab'ad.² Figure 1 shows this site in June 2003 after the undeclared program was halted. The undeclared enrichment occurred in the larger building shown. While Iran was voluntarily implementing the provisions of the Additional Protocol from 2003 to 2006, the IAEA verified that Iran did not reconstitute enrichment activities at this site.

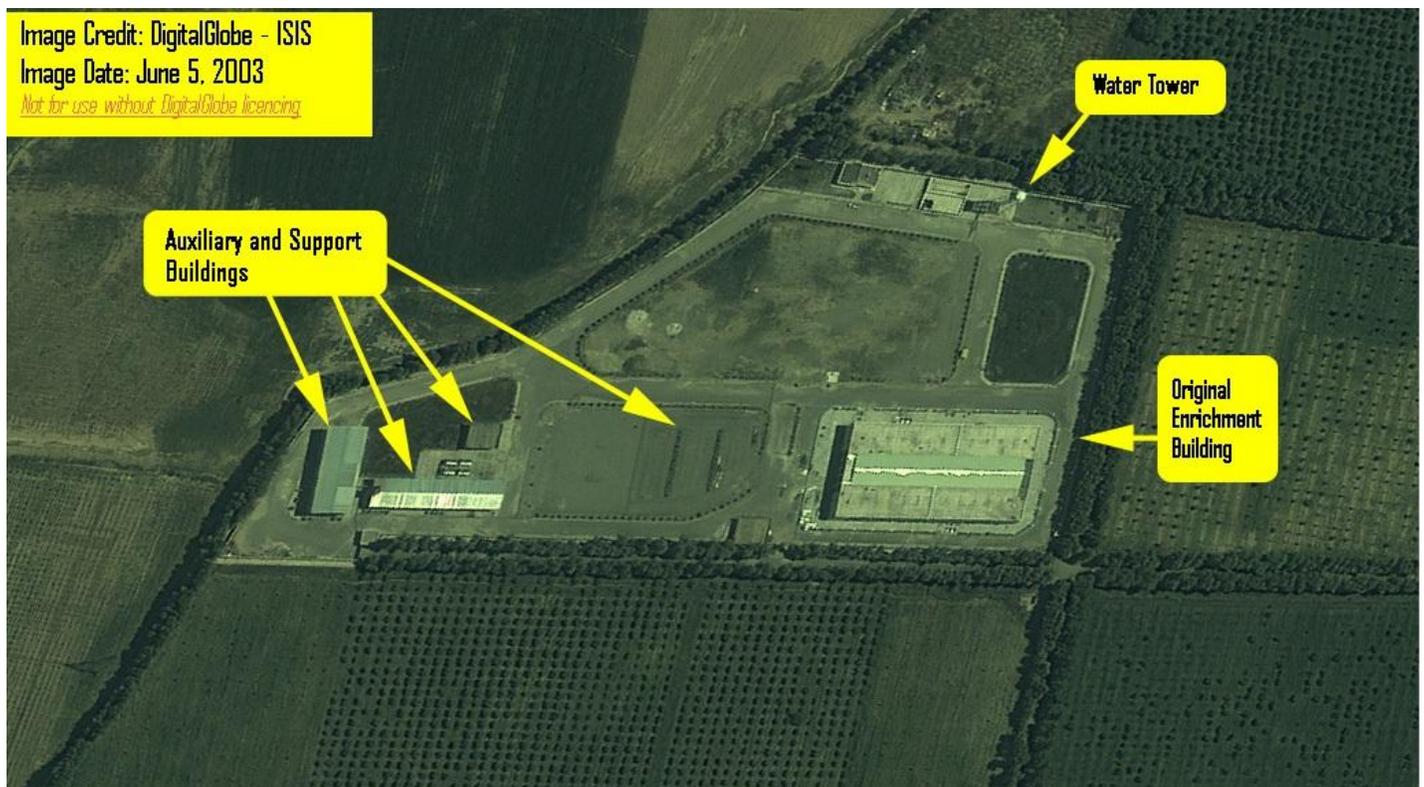


Figure 1. Digital Globe Imagery from June 5, 2003 showing the building where Iran conducted undeclared laser enrichment activities prior to May 2003. Five smaller structures are visible in the support area of the site--two support structures are in the center and three auxiliary buildings are on the far left. Internally, there are clear paths wide enough to permit the passage of vehicles and trucks. The perimeter of the site has a security wall or fencing and has one main gate (with what seems to be a guard house).

¹ Director General, IAEA, *Implementation of the NPT Safeguards Agreement in the Republic of Korea*, GOV/2004/84, November 26, 2004. <http://www.iaea.org/Publications/Documents/Board/2004/gov2004-84.pdf>; Director General, IAEA, *Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran*, GOV/2003/75, November 10, 2003.

<http://www.iaea.org/Publications/Documents/Board/2003/gov2003-75.pdf>; Director General, IAEA, *Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran*, GOV/2004/60, September 1, 2004.

<http://www.iaea.org/Publications/Documents/Board/2004/gov2004-60.pdf>; and National Monitoring Directorate, Republic of Iraq, *Draft Full, Final and Complete Declaration of the Iraqi National Nuclear Program*, February 1996.

² Location Coordinates: 35° 52' 26.01" N, 50° 45' 48.91" E.

Since 2006, Iran has allowed one IAEA visit to this site. It happened in 2008, and Iran told the IAEA its general plans for the site, including major construction projects. However, given that this visit was not an inspection, the IAEA inspectors were limited in what they could learn and verify about Iran's past and present activities.

Figure 2 is a recent image of the site, showing a greatly expanded facility. This site has conducted work on developing and manufacturing lasers and researching nanotechnology, some with the aid of lasers, according to Iranian statements and publications. A key question is whether this site engaged in activities related to enrichment of uranium after 2006.

A priority is determining whether Iran has conducted secret activities at Lashkar Ab'ad and elsewhere that are potentially related to laser enrichment. The President of Iran stated on February 7, 2010 that Iran possesses laser enrichment technology without being specific about how it achieved this capability, or where it conducted work to achieve it, particularly after 2003.³ Iran has not provided any additional information regarding this announcement, as requested by the IAEA.⁴

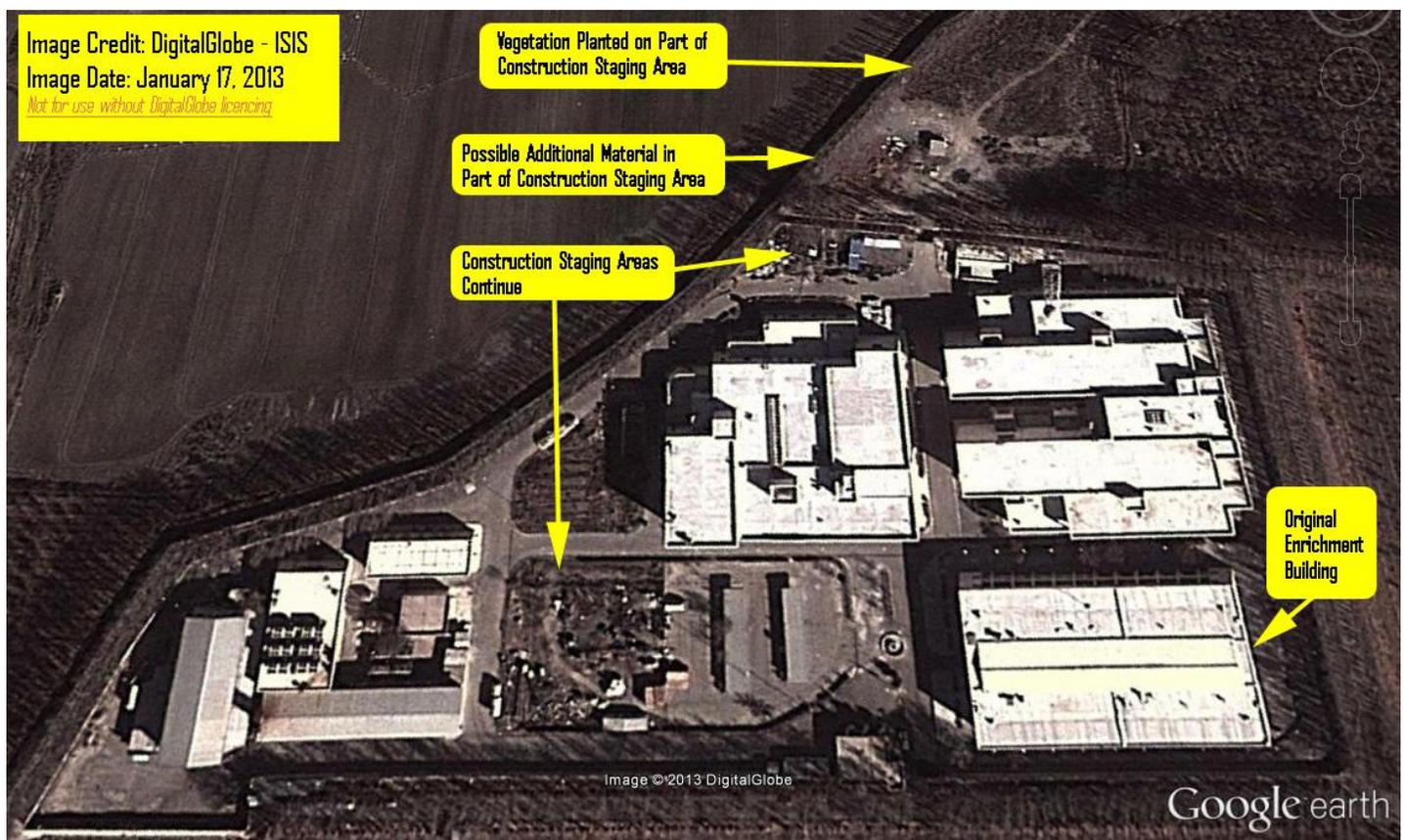


Figure 2. Early 2013 image of Lashkar Ab'ad site showing two large, new buildings. Digital Globe Imagery from January 17, 2013.

This article reviews information about Lashkar Ab'ad, more recent construction at the site, and Iran's development of advanced lasers that are suitable for use in laser enrichment. One finding is that Iran needs to clarify its February 2010 statement and allow the IAEA to fulfill its duties under the comprehensive safeguards agreement, including possibly inspecting Lashkar Ab'ad, among other sites. Iran's procurement activities

³ Cited on the website of the President of the Islamic Republic of Iran, February 7, 2010.

<http://www.president.ir/en/?ArtID=20255>

⁴ Director General, IAEA, *Implementation of the NPT Safeguards Agreement and Relevant Provisions of Security Council Resolutions in the Islamic Republic of Iran*, GOV/2013/6, February 21, 2013, p. 6.

<http://www.iaea.org/Publications/Documents/Board/2013/gov2013-6.pdf>

abroad for laser technology and equipment also require greater scrutiny and this report recommends additional controls for laser system subcomponents.

Proliferation Threat of Laser Enrichment

If properly engineered, laser enrichment has the potential to dramatically advance the capabilities of proliferant states to secretly enrich uranium. To date, however, no nuclear program is known to have successfully used laser enrichment to produce kilogram quantities of HEU or quantities of low enriched uranium (LEU) large enough for a civil nuclear reactor program.

Currently, there are three main types of laser enrichment: atomic vapor laser isotope separation or AVLIS, molecular laser isotope separation or MLIS, and separation of isotopes by laser excitation or SILEX. The last method is the newest and most promising of the three and is being developed potentially on a commercial-scale in the United States. However, there is little published information about the SILEX process, so judging its reproducibility is difficult.

In general, enriching uranium with lasers on a production-scale appears extremely complicated. However, detailed technical information about uranium laser enrichment technologies remains rather limited, making any assessment as to its feasibility more complicated. Moreover, laser enrichment appears able to make HEU, but there are disagreements about the practicality of doing so with existing methods.

Despite its difficulties, laser enrichment of uranium warrants concern as a potential way for a proliferant state to acquire significant quantities of highly enriched uranium. A covert laser uranium enrichment facility might escape detection by the IAEA and Western intelligence services.

Proliferant states, including Iran, may be motivated to consider this option for making enriched uranium possibly for nuclear weapons. Over the next five to ten years, further advances could elevate the chance that a proliferant state would use laser enrichment to produce HEU for nuclear weapons.⁵ Motivations to consider laser enrichment include major advances in laser technology, the relatively small size and the few external indicators of a laser enrichment plant, and the apparent potential of SILEX. Another motivation is a state's ability to conduct several necessary research and development activities for laser enrichment under a non-nuclear cover. Whether Iran is doing so is a core question.

Lashkar Ab'ad Laser Enrichment Plant⁶

Iran's undeclared AVLIS program was revealed in 2003 after the IAEA received information about a secret laser enrichment facility at a site near the town of Lashkar Ab'ad. After locating the site, which it did after some effort, Iran denied having a laser enrichment program.

In the spring/summer of 2003, the IAEA asked Iran for access to this undeclared nuclear site but Iran refused until August 2003.⁷ At this time Iran remained unwilling to reveal the true activities at Lashkar Ab'ad. In

⁵ David Albright, Andrea Stricker, and Houston Wood, *Future World of Illicit Nuclear Trade: Mitigating the Threat*, ISIS, to be published in July 2013.

⁶ The primary sources for this section are: *Implementation of NPT Safeguards*, November 10, 2003, op. cit., and *Implementation of NPT Safeguards*, September 1, 2004, op. cit.

⁷ Director General, IAEA, *Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran*, GOV/2003/40, June 6, 2003. <http://www.iaea.org/Publications/Documents/Board/2003/gov2003-40.pdf> and Director General, IAEA, *Implementation of the*

August 2003, Iran described the facility as “originally having been devoted to laser fusion research and laser spectroscopy, but whose focus had been changed to research and development and the manufacture of copper vapor lasers (CVLs).”⁸ It also wrote that it had had a substantial research and development program on lasers, but that it had no program for laser isotope separation.

Under intense international pressure about a range of secret nuclear activities, Iran allowed the IAEA to take environmental samples from the equipment that had been at Lashkar Ab’ad during an October 2003 visit, and the IAEA subsequently found enriched uranium on it. Faced with overwhelming evidence, Iran in late 2003 started to tell the truth about the site. The IAEA’s investigation was a major reason for Iran admitting to its undeclared laser enrichment program.

Iran made progress on undeclared laser enrichment programs because of extensive foreign assistance and illicit procurement of key technology and a range of relevant equipment and materials. It stated it had four major contracts with foreign suppliers related to laser isotope uranium enrichment using AVLIS and MLIS and used its procurement networks to acquire laser and other key equipment independent of those contracts.⁹ The first cooperation started in the 1970s with a U.S. expert but that aid was discontinued at the time of 1979 revolution. Iran’s initial steps with AVLIS involved acquiring technology and equipment from Germany. However, the first serious efforts started with Chinese cooperation that involved equipment and material slated originally for the Tehran Nuclear Research Center.

Russian Contract

The contract most important to Lashkar Ab’ad was one with Russia, which was the fourth contract. In 1998, Iran signed a contract with Russian entities to obtain information related to AVLIS and for the supply of relevant equipment for an undeclared pilot enrichment facility at Lashkar Ab’ad. However, as a result of U.S. pressure, the Russian government would not grant the Russian supplier with export permits for some of the equipment, in particular a copper vapor laser, dye lasers, some collector parts, and the power sources.

As part of the contract, the St. Petersburg Yefremov Institute (NIEFA), part of Rosatom, delivered one large vacuum chamber (5 meters long, 1 meter in diameter) equipped with some diagnostic equipment and diffusion pumps to create the high vacuum inside the chamber. The Russian supplier also provided some training and documentation. The fourth contract specified the delivery of a system that could produce enrichment levels of 3.5-7 percent and to “have actual production of at least 5 kg of a product within the first year after installation.”¹⁰ IAEA experts assessed that the system in the fourth contract could have made highly enriched uranium, albeit in very small quantities, if the entire package of equipment had been delivered.¹¹ The AVLIS vacuum chamber had a number of features specific to HEU separation work, including an ion trap for the extraction of ion impurities for increased HEU yield and a collector assembly designed for the relatively low throughput of HEU. According to a senior official close to the IAEA, at least six such chambers would have been necessary to make significant amount of weapon-grade uranium, HEU enriched over 90 percent.

The failure to obtain export permits for the Russian-made lasers did not stop Iran. Independently of these four contracts, Iran had used its overseas procurement networks to seek in Europe and perhaps the United States

NPT Safeguards Agreement in the Islamic Republic of Iran, GOV/2003/63, August 26, 2003.

<http://www.iaea.org/Publications/Documents/Board/2003/gov2003-63.pdf>

⁸ *Implementation of NPT Safeguards*, November 10, 2003, op. cit., par. 36.

⁹ For a summary of these contracts, see *Future World of Illicit Nuclear Trade: Mitigating the Threat*, op. cit.

¹⁰ *Implementation of NPT Safeguards*, September 1, 2004, op cit, Annex p. 8.

¹¹ *Implementation of NPT Safeguards*, September 1, 2004, op cit, Annex p. 8.

needed goods for its laser enrichment programs, in particular copper vapor and dye lasers. Moreover, under an earlier laser enrichment contract, China had secretly supplied 50 kilograms of natural uranium metal in the early 1990s, which Iran failed to declare to the IAEA as required under its safeguards agreement.¹² This uranium metal was intended for use as the feed material in AVLIS laser enrichment experiments. It was critical since Iran had encountered difficulties in making purified uranium metal at that time. Iran also obtained electron beam guns from Russia and China that were for use in an AVLIS program.

Iran installed its previously imported copper vapor lasers and dye lasers with the large vacuum vessel at Lashkar Ab'ad in 2002, according to Iranian declarations to the IAEA. Iran conducted a total of four runs with the Chinese-supplied uranium metal feed using a total of 500 grams of uranium from October 2002 through January 2003, achieving enrichment levels of 0.8 percent.¹³

The head of the AVLIS project at Lashkar Ab'ad was laser expert Jamshid Sabbaghzadeh, according to a former senior official close to the IAEA. He was also the counterpart to the Russian side of the laser enrichment contract. He obtained his doctorate in the United States.

As part of its effort to hide its activities at Lashkar Ab'ad, Iran dismantled the equipment in May 2003, although not the lasers, and transferred this equipment together with the uranium metal to the Karaj nuclear site. The IAEA later inspected both sites to ensure the program was not reconstituted. In 2004, Lashkar Ab'ad's decommissioned AVLIS pilot plant was monitored through complementary access under the Additional Protocol, and Karaj's dismantled AVLIS and MLIS related equipment was subject to inspection, Design Inventory Verification (DIV) visits and complementary access.¹⁴ IAEA laser enrichment experts visited the site in April/May 2004.

However, given Iran's decision to cease the implementation of the Additional Protocol in February 2006, the IAEA from that date has gained limited additional information relating to any additional activities or construction at Lashkar Ab'ad or elsewhere. Consequently, the Agency's ability to access activities not involving nuclear material, such as Iran's research into laser isotope separation, has been inhibited.¹⁵

2008 IAEA Visit

On February 5, 2008, senior IAEA officials visited the Lashkar Ab'ad site as part of an effort by Iran to be more transparent, albeit without granting the transparency in the Additional Protocol or for that matter mandated by its comprehensive safeguards agreement. Iran stated to the IAEA that the laboratories were run by a supposed private company that was developing and producing laser equipment for industrial purposes.¹⁶ The Iranians told IAEA officials that all the former laser equipment associated with the earlier laser enrichment program had been dismantled; some of it was stored at the site. The management of the private company provided the IAEA with information on its activities and its plans for extensive new construction work. They

¹² *Implementation of NPT Safeguards*, November 10, 2003, op. cit. and *Implementation of NPT Safeguards*, September 1, 2004, op. cit.

¹³ *Implementation of NPT Safeguards*, November 10, 2003, op. cit. and *Implementation of NPT Safeguards*, September 1, 2004, op. cit.

¹⁴ Director General, IAEA, *Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran*, GOV/2004/11, February 24, 2004, par.65. <http://www.iaea.org/Publications/Documents/Board/2004/gov2004-11.pdf>

¹⁵ Director General, IAEA, *Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran*, GOV/2006/27, April 28, 2006, par. 35. <http://www.iaea.org/Publications/Documents/Board/2006/gov2006-27.pdf>

¹⁶ Director General, IAEA, *Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran*, GOV/2010/46, September 6, 2010, p. 5, par. 18. <http://www.iaea.org/Publications/Documents/Board/2010/gov2010-46.pdf>

also stated that they were not carrying out or planning to carry out any uranium enrichment activities at the site.

At the time of the visit, the old enrichment building housed laser research and manufacturing (see figure 1). The Iranians were producing large copper vapor lasers and neodymium doped, yttrium aluminum garnet (Nd:YAG) lasers but not dye lasers. Extensive laser work was expected to continue at Lashkar Ab'ad.

One of the new buildings was slated to hold a large nanotechnology center, which was also to include the use of lasers in researching nanotechnology. It was to be headed by Jamshid Sabbaghzadeh, the former head of the AVLIS laser enrichment program at Lashkar Ab'ad, according to a former senior official close to the IAEA. Other scientists and engineers from the dismantled AVLIS program also reportedly continued working at the expanding Lashkar Ab'ad site.

Satellite Imagery Shows Growth of Site

Is Iran today continuing its work on laser enrichment at Lashkar Ab'ad? Commercial satellite imagery documents significant growth in the Lashkar Ab'ad site starting in 2008 and extending into early 2013. However, these images do not provide an indication of when the buildings were inaugurated or what is done inside them.

A baseline is provided by Figure 1 (above) from June 2003, long before construction was resumed. Figures 3-10 trace the construction of two new buildings at the site from May 2008 until early 2013.



Figure 3. In May 2008, several changes are visible. The foundations for new buildings are now clear. Two construction staging areas appear (with construction material as well). A new auxiliary building appears at the center of the image. In addition, visible are a water tower (to the far right) and an addition to the existing auxiliary building (to the far left). The perimeter is surrounded by a

security wall or fencing. There also appears to be one main gate with a guard house (bottom right of image). There appears to be another gate that leads to the construction staging area. Digital Globe Imagery from May 22, 2008.

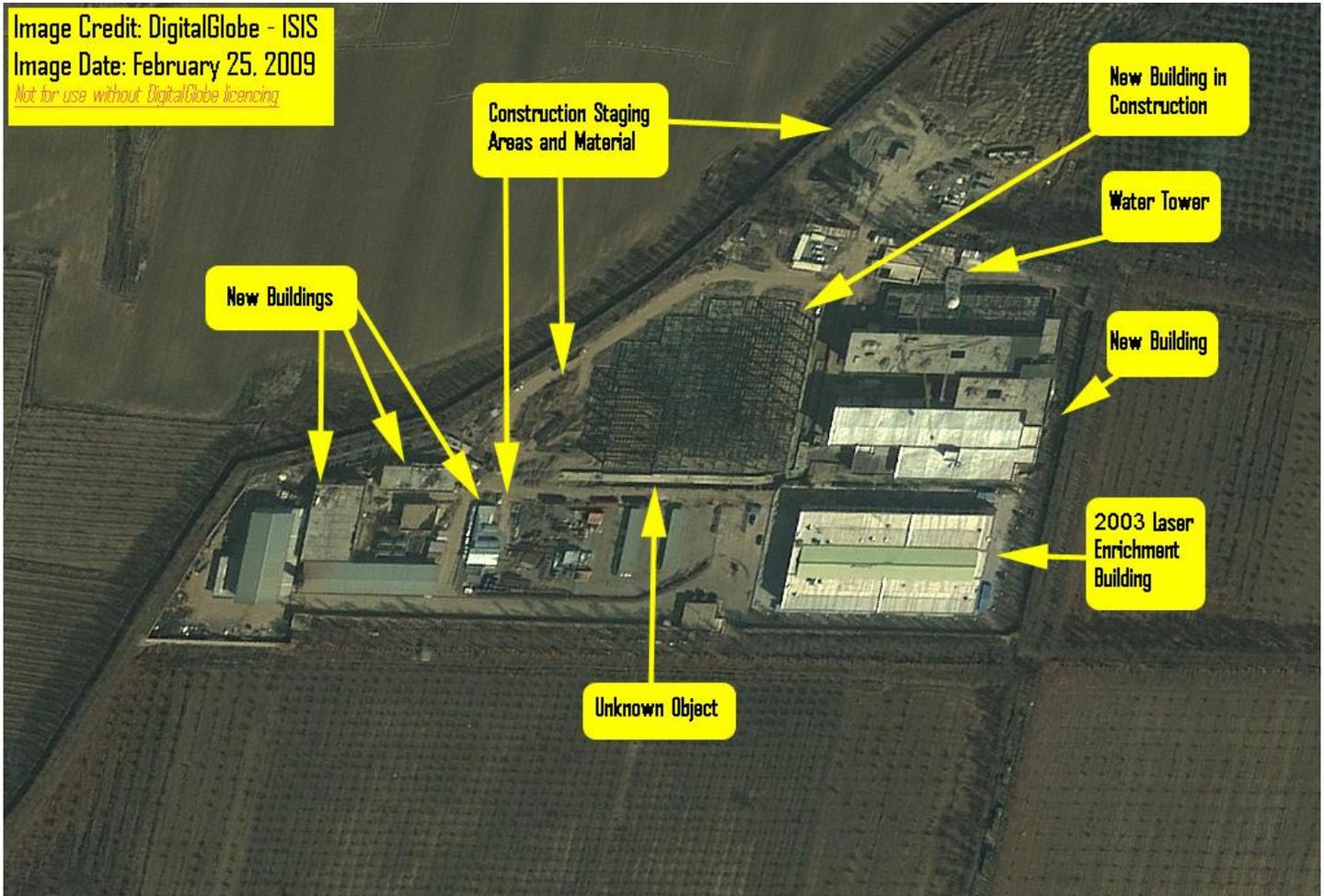


Figure 4. In February 2009, the two new buildings emerge. One is almost complete (on the far right) and one is under construction (center). Three new buildings, possibly auxiliary ones, appear on the left of the image, while an auxiliary building previously shown has disappeared. A long light colored object can be seen on the edge of the newest building. It appears to be under ground, or at ground level, in an excavated area. It looks as if it would be covered later. It is not known what this object is. Digital Globe Imagery from February 25, 2009.

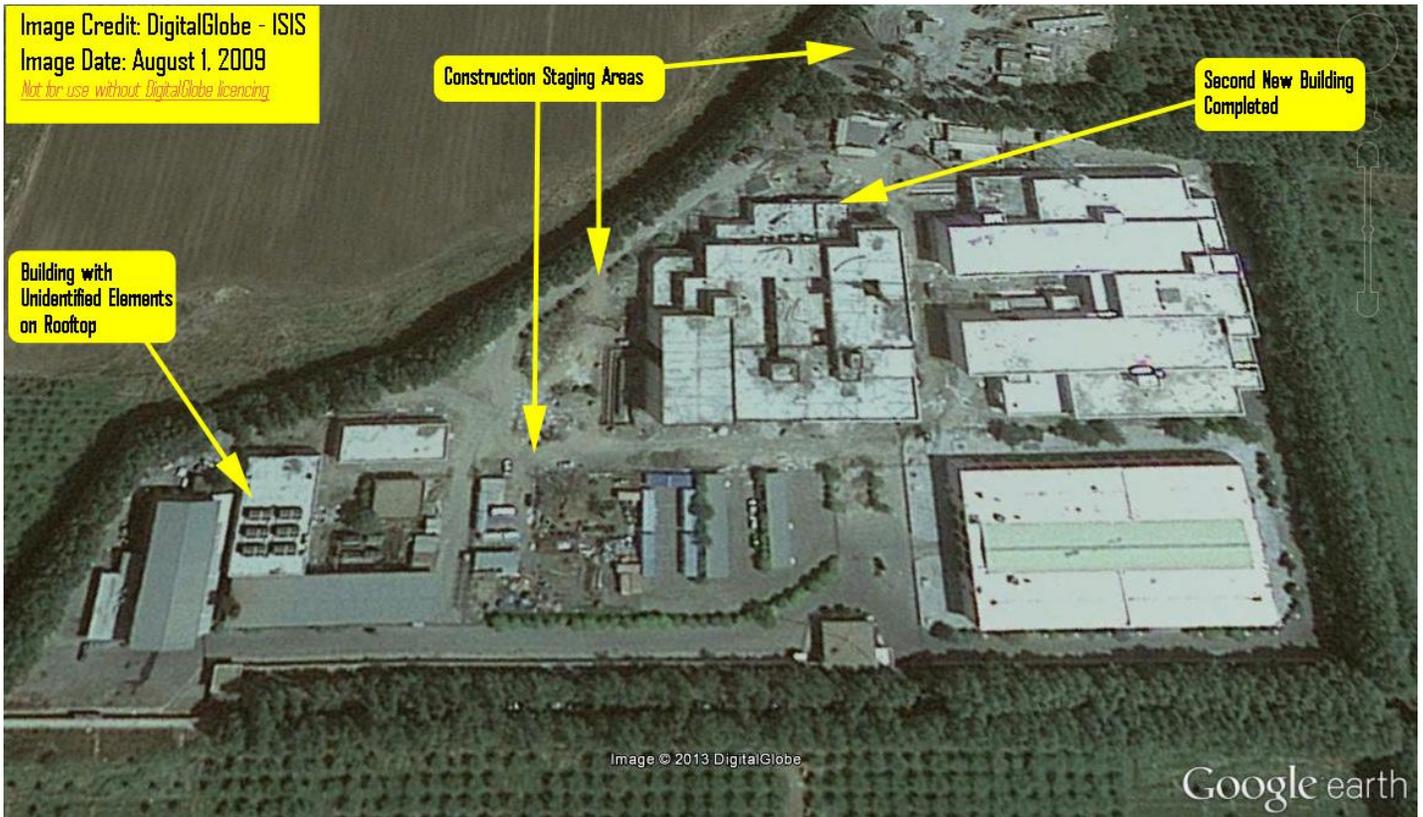


Figure 5. In August 2009, the preexisting construction staging areas and materials remain. The two new large buildings are now clearly visible. A new construction staging area and material are at the center of the image. The original laser enrichment building is at the bottom right of the image. Digital Globe Imagery from August 1, 2009.

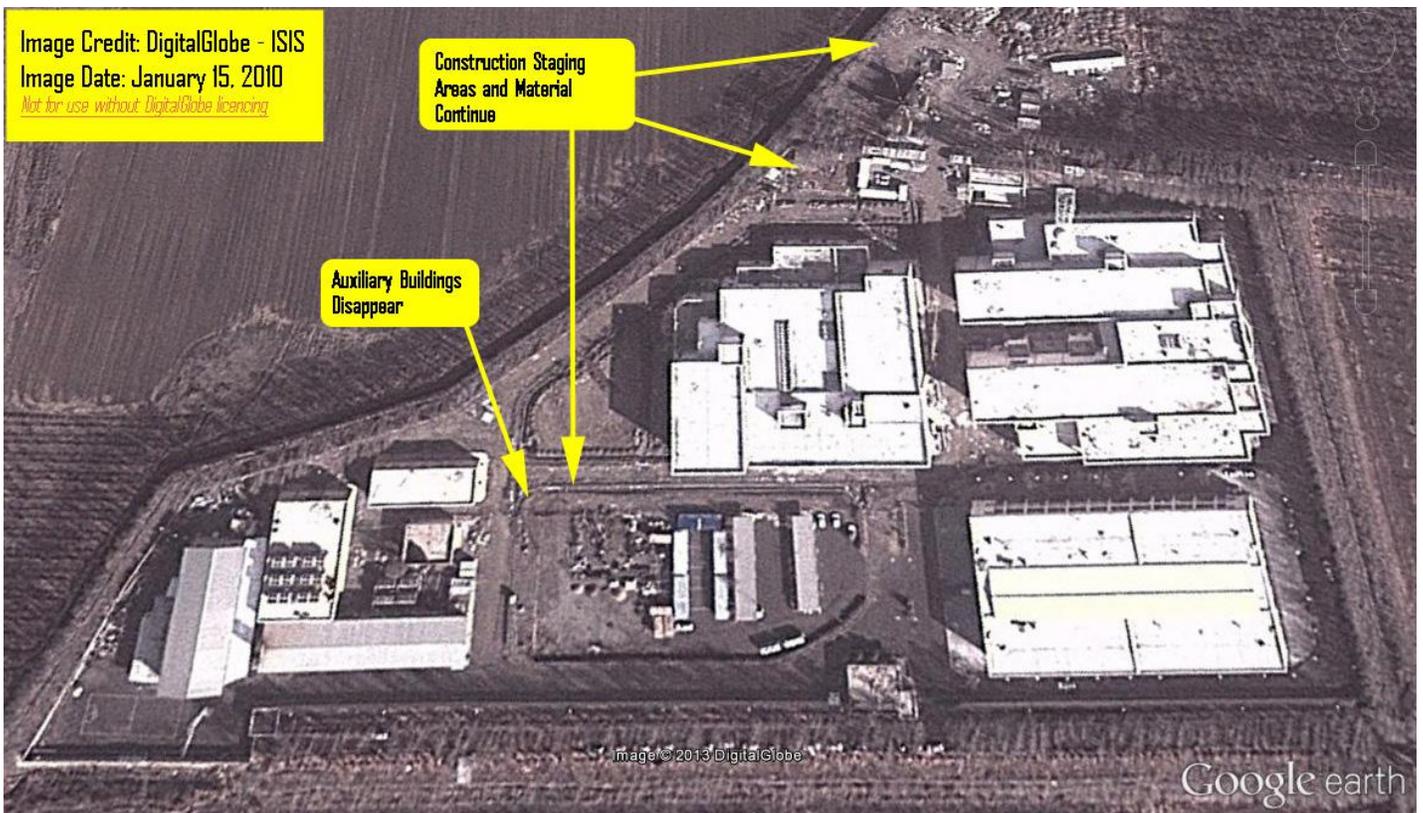


Figure 6. In January 2010, the two new buildings appear more finished externally. The image shows the existing construction staging areas while some of the preexisting auxiliary buildings have disappeared. Digital Globe Imagery from January 15, 2010.

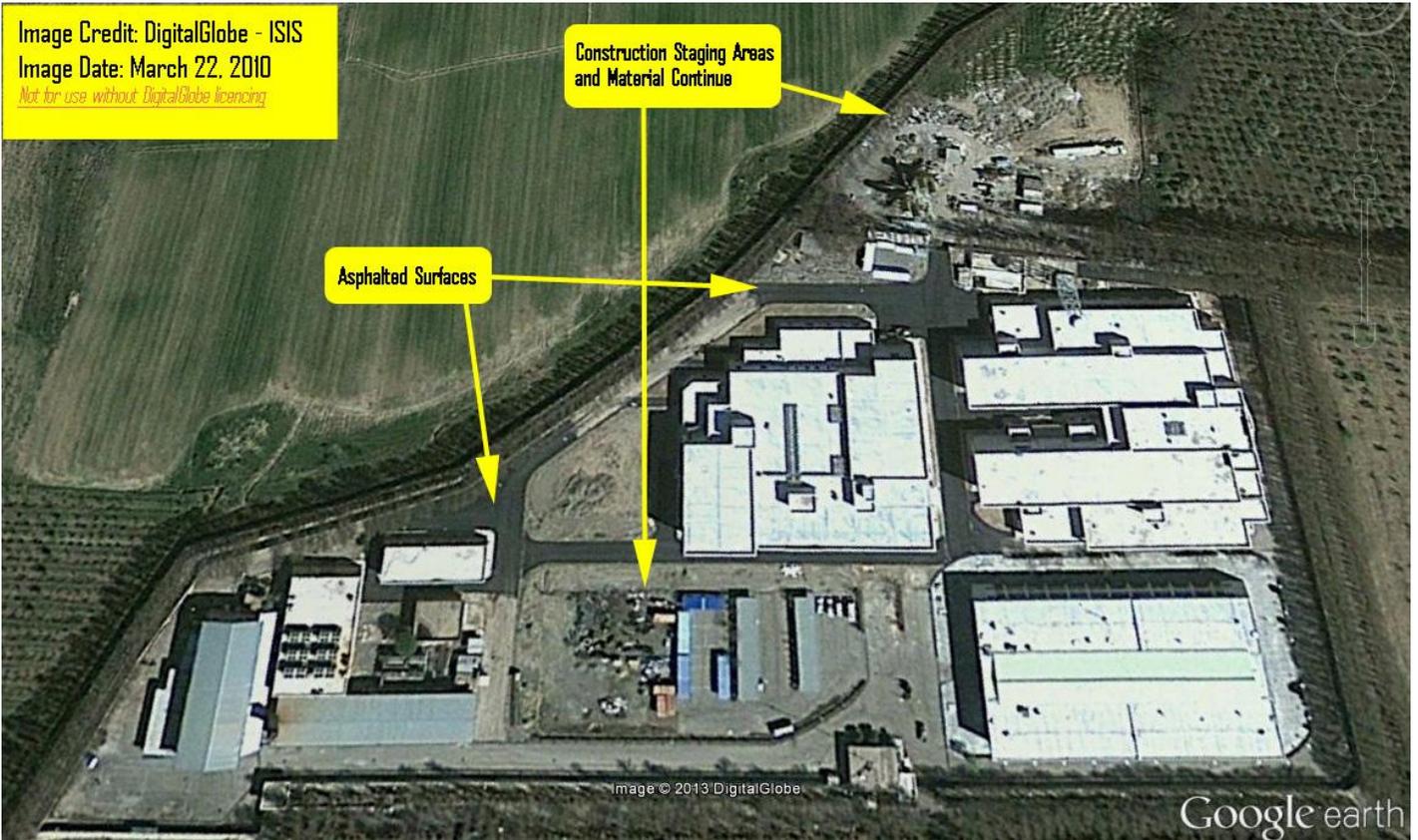


Figure 7. In March 2010, while the construction staging areas and material continue to be present, it is also clear that several surfaces have been asphalted. Digital Globe Imagery from March 22, 2010.

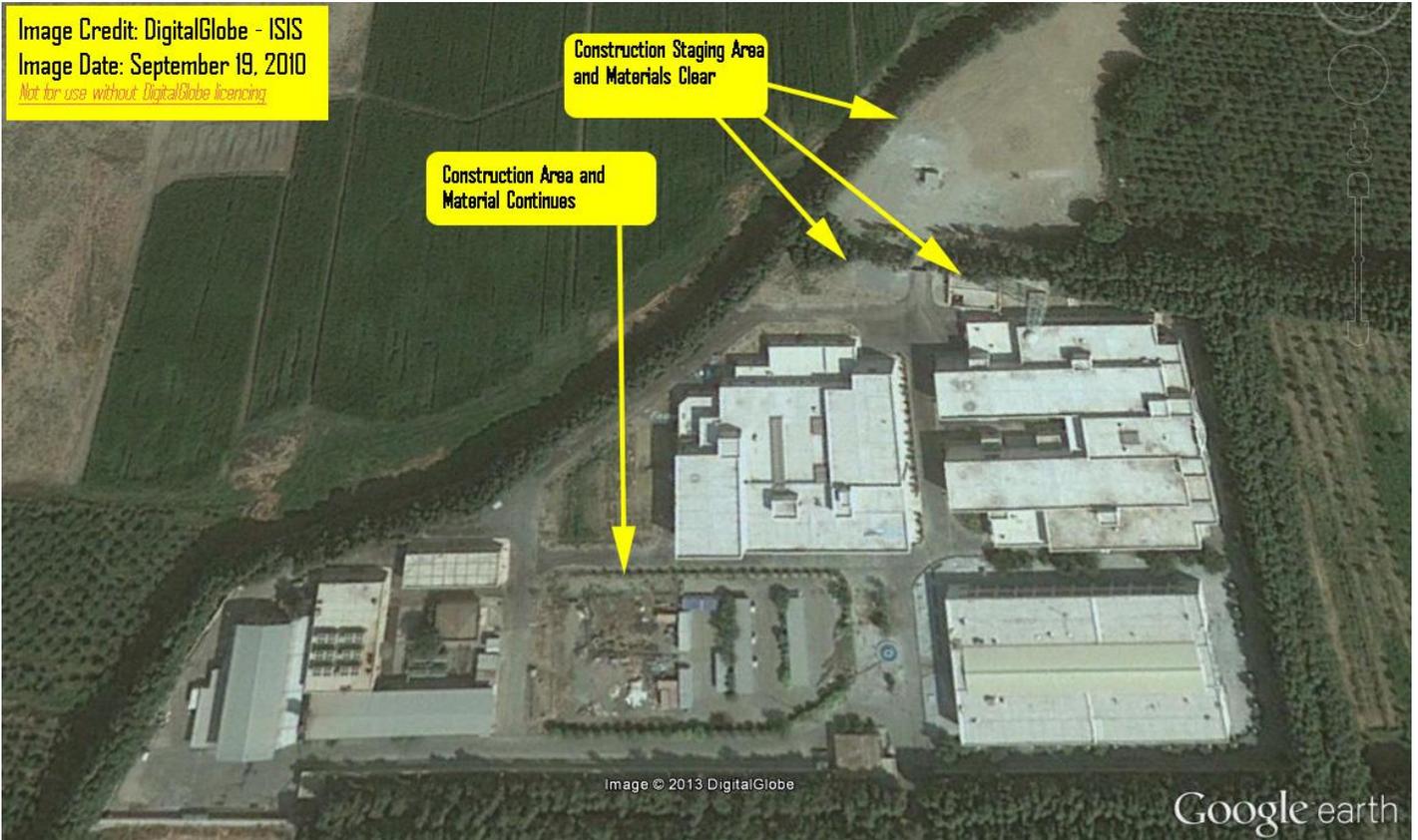


Figure 8. A September 2010 image shows that the construction area and materials continue to exist at the center of the image, but the other areas and materials seem to have been cleared. Digital Globe Imagery from September 19, 2010.

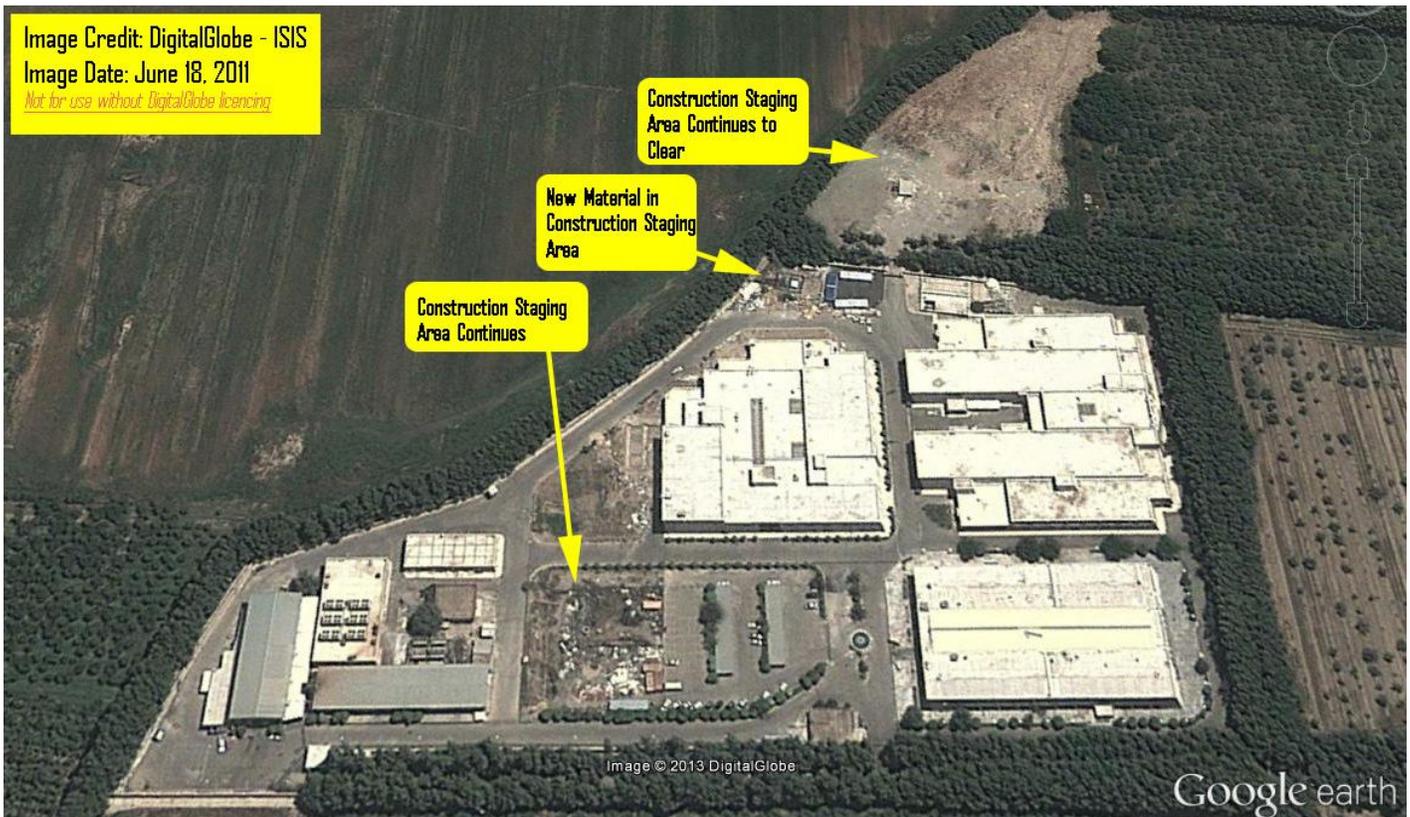


Figure 9. In June 2011, while the construction staging area in the upper part of the image seems to remain clear, the one in the lower part shows new construction material. Additionally, the construction staging area at the center remains. Digital Globe Imagery, June 18, 2011.

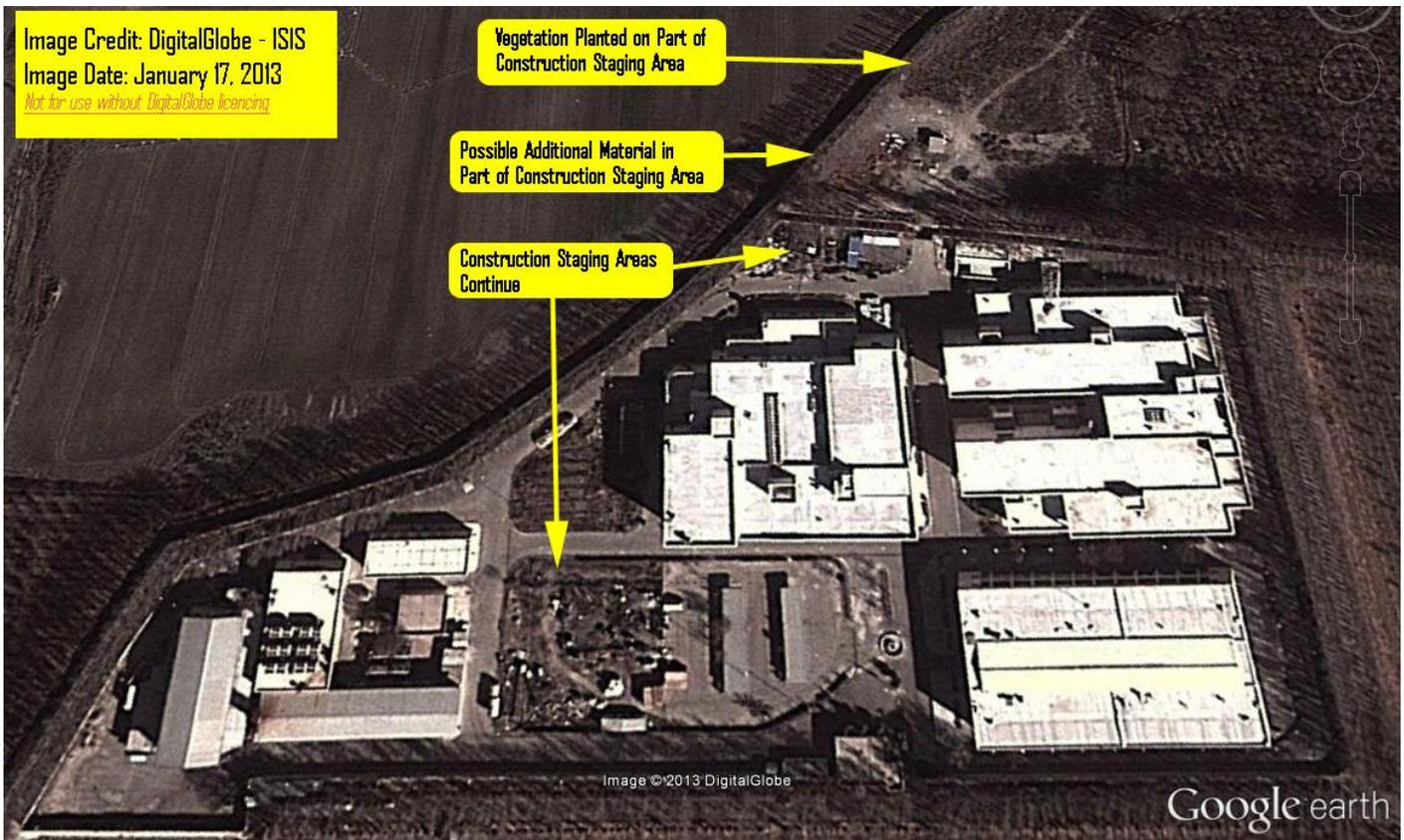


Figure 10. January 2013 imagery shows the two main construction staging areas. However, possible additional material seems to be present in the previously cleared construction staging area, while part of it also seems to have been covered by vegetation. Thus, it does not appear that construction is completely finished. Digital Globe Imagery from January 17, 2013.

Paya Partov

While the construction of the new buildings at Lashkar Ab'ad was occurring the site appears to have remained active. As mentioned above, the original laser enrichment building at the site continued with laser work, according to the IAEA.

After its 2008 visit, the IAEA also reported on a private company operating at Lashkar Ab'ad. However, it should be noted that calling an Iranian company private may not mean that this entity is a private company in the Western economic sense or that it is independent of the Atomic Energy Organization of Iran (AEOI) or other Iranian government entities. In fact, this private company is believed to be a government associated entity and is better referred to as a research center.

The private company mentioned by the IAEA is not named, but the only candidate for this company appears to be the Paya Partov Laser Research Centre. This research center appears to have been active at Lashkar Ab'ad and in Tehran. Moreover, Sabbaghzadeh published under this center and likely headed it.

ISIS collected numerous scientific journal articles and conference proceedings that show that since 2006, people affiliated directly with Paya Partov Laser Research Center, including Sabbaghzadeh, published papers related to laser research activities. A sampling of them shows the links between the authors and Paya Partov:

- In 2006, M. J. Torkamany and Sabbaghzadeh were both listed as affiliated with Paya Partov Laser Research Center in the paper *"The Effect of Process Parameters on Keyhole Welding with a 400 W Nd : YAG Pulsed Laser."*¹⁷
- In 2007, Sabbaghzadeh and S. Ebrahimi published *"Effective Thermal Conductivity of Nanofluids Containing Cylindrical Nanoparticles,"* listing their affiliation with Paya Partov Laser Research Center.¹⁸
- In 2007, the Chemistry and Nanotechnology Group associated with Paya Partov, including author Sabbaghzadeh published *"Nanolayer Effects in Thermal Conductivity of Nanofluids Containing Cylindrical Nanoparticles,"*¹⁹ while Sabbaghzadeh, M. Azizi, and J. Torkamany listed themselves as affiliated with Paya Partov in *"Numerical and Experimental Investigation of Seam Welding with a Pulsed Laser."*²⁰
- Also in 2007, Sabbaghzadeh and two other authors published *"468-W CW Operation of a Diode-Pumped Nd: YAG Rod Laser with High Beam Quality and High Efficient Concentrator of Pump Light."*²¹ However, this time, the authors were affiliated with both Paya Partov Laser Research Center and the National Science and Technology Research (NSTR) Institute at the Atomic Energy Organization of Iran (AEOI). This may signify that the two institutions were cooperating or the authors had dual appointments.
- In 2009 several authors affiliated with Paya Partov and the AEOI's NSTR Institute published *"Effects of Ultrasound Radiation on the Synthesis of Laser Ablated Gold Nanoparticles"*²² and *"Synthesis of Multi-Wall*

¹⁷ M. J. Torkamany, M. J. Hamedi, F. Malek, J. Sabbaghzadeh, "The Effect of Process Parameters on Keyhole Welding with a 400 W Nd : YAG Pulsed Laser," *Journal of Physics D: Applied Physics*, Volume 39, Issue 21, November 2006, pp. 4563-4567.

¹⁸ J. Sabbaghzadeh and S. Ebrahimi, "Effective Thermal Conductivity of Nanofluids Containing Cylindrical Nanoparticles," *International Journal of Nanoscience*, Volume 6, Issue 1, February 2007.

¹⁹ S. Ebrahimi, J. Sabbaghzadeh, M. Lajvardi, I. Hadi, "Nanolayer Effects in Thermal Conductivity of Nanofluids Containing Cylindrical Nanoparticles," *Nanotechnology*, 2007. IEEE-NANO 2007.

²⁰ J. Sabbaghzadeh, M. Azizi, J. Torkamany, "Numerical and Experimental Investigation of Seam Welding with a Pulsed Laser," *Optics & Laser Technology*, Volume 40, Issue 2, March 2008, pp. 289-296.

²¹ J. Sabbaghzadeh, I. Rahimzadeh, I. Mashayekhe, "468-W CW Operation of a Diode-Pumped Nd: YAG Rod Laser with High Beam Quality and High Efficient Concentrator of Pump Light," *Optics and Laser Technology*, Volume 40, 2008.

²² S. Dadras, P. Jafarkhani, M. J. Torkamany, J. Sabbaghzadeh, "Effects of Ultrasound Radiation on the Synthesis of Laser Ablated Gold Nanoparticles," *Journal of Physics*, Volume 42, N. 2, 2009.

*Carbon Nanotubes by Copper Vapor Laser.*²³ Again, in the former publication, Sabbaghzadeh is listed as affiliated with both entities.

- In 2010, Torkamany under the Paya Partov affiliation published with three other colleagues “A Numerical and Experimental Study of Sheet Metal Bending by Pulsed Nd:YAG Laser with DOE Method.”²⁴

Torkamany also published a paper in 2006, where he listed his affiliation with Paya Partov Industrial and Medical Laser Company.²⁵ A coauthor was listed as with the Laser Research Center, AEOI.

In almost all cases, the papers listed the address of those affiliated with Paya Partov as a Tehran post office box.²⁶ They did not provide a street address of the center.

According to a former senior official close to the IAEA, senior employees at Lashkar Ab’ad also worked in Tehran part of the week. They worked at Lashkar Ab’ad about four days a week and at a Tehran office the other one or two days per week. So, the provision of a Tehran P.O. Box address may be part of a policy not to list the address of Lashkar Ab’ad, effectively hiding it.

As shown in these scientific publications, Sabbaghzadeh was directly associated with the Paya Partov Laser Research Center, which is strongly believed to have operated at Lashkar Ab’ad, and be associated in some manner with the NSTR Institute at the AEOI. This would confirm Iran’s statements that Sabbaghzadeh continued to work on lasers. It also is consistent with Iran continuing with its research on lasers, their applications, and laser manufacturing at Lashkar Ab’ad under the auspices of the Atomic Energy Organization of Iran.

Based on the available information, the AEOI appears to still own Lashkar Ab’ad, and the Paya Partov Laser Research Center appears closely associated with the AEOI, more closely than Iran’s identification of it as a private company suggests. It was for this reason, among others, that Paya Partov was suspected of undertaking secret laser enrichment activities as early as 1996.

On November 11, 2011, the United States sanctioned Paya Partov. According to the Treasury Department, Paya Partov was “in charge of all research related to laser enrichment and plays a crucial role in Iran's uranium enrichment efforts. Laser enrichment was adopted as one of three courses of action by the Iranian regime for the purpose of acquiring nuclear weapons.”²⁷

²³ J. Sabbaghzadeh, P. Jafarkhani, S. Dadras, M. J. Torkamany, “Synthesis of Multi-Wall Carbon Nanotubes by Copper Vapor Laser,” *Applied Physics A*, Volume 94, Issue 2, February 2009, pp 293-297.

²⁴ M. Hosseinpour Gollo, H. Moslemi Naeini, G. H. Liaghat, S. Jelvani, M. J. Torkamany, “A Numerical and Experimental Study of Sheet Metal Bending by Pulsed Nd:YAG Laser with DOE Method,” *Advanced Materials Research*, Volumes 83-86, 2010, pp. 1076-1083.

²⁵ M. J. Torkamany, M. Kaviani, M. Zand, “Experimental Study of Sealed Off Operation of a High Repetition Rate TEA CO₂ Laser,” *Laser Physics Letters*, Volume 3, N. 10, October 2006, p. 480. The study does not provide Torkamany’s address but a Tehran P.O. Box 173277288.

²⁶ One study submitted in 2006 listed the address of Paya Partov Laser Research Center as Saadat Abad, Kaj Square, East Sarv Avenue, No. 45, Tehran, Iran. See J. Sabbaghzadeh and S. Ebrahimi, “Effective Thermal Conductivity of Nanofluids Containing Cylindrical Nanoparticles,” *International Journal of Nanoparticles*, Volume 6, Issue 1, February 2007. The address given for this center in the 2011 Treasury Department factsheet is different (see footnote 27).

²⁷ Department of the Treasury Designations under E.O. 13382. http://www.treasury.gov/resource-center/sanctions/OFAC-Enforcement/Documents/11212011_iran_wmd_factsheet.pdf

Earlier, in May 2011, Paya Partov, was designated by the European Union as a subsidiary of Novin Energy, which was designated by the U.S. Treasury Department on January 4, 2006 for being owned or controlled by the AEOL.²⁸

Iranian National Center of Laser Science and Technology Research

After Paya Partov was identified as linked to a secret laser enrichment program in the late 2000s, scientists who used to list their affiliation with Paya Partov switched to another center. Although U.S. sanctions date to 2011, the linkage of Paya Partov to secret laser enrichment activities started several years earlier, likely necessitating Iran to create a new institute name.

The new institute, which is headed by Jamshid Sabbaghzadeh, is the Iranian National Center of Laser Science and Technology (INLC).²⁹ The name of this institute first started to appear publicly in the late 2000s, according to Mark Gorwitz, an ISIS consultant and expert in researching open source technical literature. The exact relationship between this center and Paya Partov is not stated by Iran, although it is likely a successor organization to Paya Partov. Some evidence supporting this assessment is that on several publications of those affiliated with the National Center of Laser Science and Technology, the address is given only as P.O. Box 14665-576, which coincides exactly with the P.O. Box of Paya Partov Laser Research Center.

Another key scientist, Javad Torkamany, listed in his publications as affiliated with both centers, posted on his LinkedIn profile another indication that Paya Partov had become INLC. As of July 2013, he had listed himself as supervisor of Laser Material Processing Laboratory at the INLC and states that he has worked on the design and construction of metal vapor lasers, Nd:YAG lasers, and TEA CO₂ lasers.³⁰ He is also familiar with light/matter interactions, materials processing with high power lasers, pulsed laser welding, and nanoparticle generation by laser ablation in liquids. He then states that he was supervisor of the Laser Material Processing Laboratory at the INLC from September 2007 to the present (5 years 11 months).³¹ He also states he was a researcher at the INLC from 2007 to the present (6 years) in the Laser Material Processing laboratory. Since his publications from as late as 2009 list him at the Paya Partov Laser Research Center for the very work he discusses in his LinkedIn profile, it is reasonable to assess that the INLC was a successor organization to the Paya Partov Laser Research Center, where Torkamany chooses not to flag his earlier affiliation with the now sanctioned center.

Thus, the INLC is likely a successor organization to Paya Partov. The aim is likely to avoid complications from being affiliated with an organization said to conduct secret enrichment work.

Moreover, INLC's main facility is likely located at Lashkar Ab'ad. Figure 11 is a photo of the INLC from its web site. Comparing this photo to commercial satellite imagery of Lashkar Ab'ad (see figures above) shows striking similarities, where the INLC's banner with its logo hangs on the original enrichment building. The number, shape, and position of the buildings coincide. The location of the water tower is the same. Certain other objects coincide, including the trees visible on the far right and left in figure 11 and the lamp post on the left

²⁸ Council Implementing Regulation N. 503/2011, "Implementing Regulation N. 961/2010 on Restrictive Measures Against Iran." <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:136:0026:0044:EN:PDF>

²⁹ Institute of Nanotechnology web site, "Laser-Assisted Synthesis of Gold-Silver Nanochains," June 30, 2011. <http://www.nano.org.uk/news/1513>

³⁰ ISIS search of Javad Torkamany's LinkedIn account, July 2013.

³¹ The homepage of the INLC web site lists the center's startup date as 1385 in the Persian calendar which corresponds to 2006-2007.

(in front of original enrichment building). In addition, there is also a match in the stair-like shaped pavement in front of the original enrichment building's entrance.



Figure 11. Site of INLC. Its banner with logo hangs on the original enrichment building at Lashkar Ab'ad. Source: Archived INLC web site. The date of the photograph appears to be in 2010 or later.

February 2010 Announcement

President Mahmoud Ahmadinejad's announcement that Iran possessed laser enrichment technology in February 2010 occurred at a major exhibition sponsored by Iran's National Center for Laser Science and Technology. This inaugural ceremony showcased Iran's achievements in the field of laser science and displayed high-tech laser instruments developed by Iranian researchers. The web site of the INLC advertises a range of laser based products for civil applications.³²

Ahmadinejad told the conference: "Today, we are capable of enriching uranium with lasers. It is now possible to do this using the same devices which are on display here in this exhibition."³³ He added that "using the laser technology for enriching uranium would lead to carrying out the enrichment process with a higher quality, accuracy and speed."³⁴ However, he also stated that "the Iranian scientists have acquired the laser-

³² The Iranian National Center for Laser Science and Technology had a web site address but it has since been removed. Copies of the web site are available from 2010 to June 2013. However, the links do not work in the copies from 2012 and 2013. See: http://web.archive.org/web/20110601000000*/http://inlc.ir

³³ "Iran's Latest Achievements in Laser Technology," Iran Press TV video, February 8, 2010. <http://www.youtube.com/watch?v=8snVESyzvK4>

³⁴ "Good Nuclear News, Iran Possesses Laser Enrichment Technology," Presidency of the Islamic Republic of Iran Website, February 7, 2010, <http://www.president.ir/en/20255>

operating uranium enrichment know-how but would put the technology on shelf for the moment.”³⁵ He highlighted that given that Iran was using centrifuges for enriching uranium it would not use its laser technology for enrichment.³⁶ But with Iran’s long experience at subterfuge about its nuclear activities, this pledge must be treated skeptically absent stringent IAEA verification. Moreover, this announcement raises questions about how and where Iran acquired this capability.



Figure 12. Images from the February 7, 2010 inaugural exhibition of the INLC. Clockwise from top left: President Mahmoud Ahmadinejad addresses participants of the exhibition. Jamshid Sabbaghzadeh cuts the ribbon at the exhibition. Ali Larijani, Chairman of the Parliament, speaks to reporters at the exhibition. Then head of the AEOI, Ali Akbar Salehi (far left), and the President listen to other speakers at the exhibition.

During the conference, Sabbaghzadeh told Iran Press TV, “The government and the president are supporting us.”³⁷ Important current and past nuclear officials attended the exhibition (see figure 12).

This conference in essence linked this new center to the achievement of a laser enrichment capability. Assuming that Ahmadinejad was not acting unilaterally, perhaps the overall goal was to project a technical nuclear capability internationally, albeit one that he claimed would not be implemented, while launching a “new” center that did not have the growing baggage of Paya Partov.

Sabbaghzadeh also told Press TV, “I think we will soon be able to produce a wide range of lasers in demand inside the country.”³⁸ INLC made clear at the conference that it aims to bring “full independence” to the laser

³⁵ “Iran Scientists Gain Full Access to Laser Tech,” Islamic Invitation Turkey, February 8, 2010. The article in the footnote says: “Hours before when inspecting the exhibition, the President said that the Iranian scientists have acquired the laser-operating uranium enrichment know-how but would put the technology on shelf for the moment.”

³⁶ “Good Nuclear News, Iran Possesses Laser Enrichment Technology,” op.cit.

³⁷ “Iran’s Latest Achievements in Laser Technology,” op. cit. For a slightly different translation to English, see “Iran Holds 1st Fully Domestic Laser Exhibit,” Islamic Invitation Turkey, Feb. 8, 2010

³⁸ “Iran’s Latest Achievements in Laser Technology,” op. cit. For a slightly different translation to English, see “Iran Holds 1st Fully Domestic Laser Exhibit,” op. cit.

sector.³⁹ Iran started localizing its laser technology only three years prior to the exhibition, according to this laser center.⁴⁰ However, this confirms that prior to this date Iran had continued importing laser related goods from abroad, possibly in violation of sanctions or national export controls. Moreover, Iran has likely remained dependent on obtaining certain advanced laser components abroad and will undoubtedly remain so for many years.

For example, according to a former senior official close to the IAEA, Iran was buying electronic switches, or thyratrons, for laser systems abroad. It likely has bought other components as well. For example, overseas purchases of laser subcomponents could also include Q-switches or frequency doublers, diode bars, and possibly power supplies.

Advanced Lasers

In general tracking any Iranian progress on laser enrichment is very complicated, absent IAEA verification. One area that can at least be partially scrutinized involves Iran's work on advanced lasers.

Iran has developed considerable expertise in lasers and is devoting significant resources to their development. Some progress can be roughly ascertained by evaluating its recent scientific publications on Nd:YAG lasers. These lasers are used in AVLIS programs as a replacement for copper vapor lasers. The Iranian publications show that both the National Center for Laser Science and Technology and the Laser and Optics Research School have placed a priority in developing high power solid state Nd:YAG lasers. Both have advanced lasers that can be used in laser enrichment of uranium.

In the last several years, Iran's National Center for Laser Science and Technology has prioritized the advancement of Iran's lasers and the applications of lasers to a wide range of fields, including medical, industrial, nanotechnology, fusion, defense, and nuclear. It is developing Nd:YAG lasers of a type and power adequate for AVLIS use, despite being developed for medical purposes.⁴¹

In addition to the INLC, the Laser and Optics Research School, formerly called the Laser Research Center, at the AEOI in Tehran, is also active. As stated above, this group is under the AEOI's Nuclear Science and Technology Research Institute. They have developed solid state Nd:YAG lasers for medical applications similar to those being developed at the INLC, according to a 2011 publication.⁴² These Nd:YAG lasers also have characteristics that would make them suitable for use in AVLIS. In that 2011 publication, the lead author Hajiesmaeilbaigi was also a coauthor of a 2005 article with J. Sabbaghzadeh on what appears to be an earlier version of this same type of laser.⁴³ This article shows an earlier link between these two important laser scientists.

³⁹ "Iran's Latest Achievements in Laser Technology," op. cit.

⁴⁰ "Iran Holds 1st Fully Domestic Laser Exhibit," op. cit.

⁴¹ H. Bazayar, M. Aghaie, M. Hossein Daemi, S. Bagherzadeh Morteza, "Compact 151W Green Laser with U-Type Resonator for Prostrate Surgery," *Optics and Laser Technology*, Volume 47, April 2013, pp. 237-241.

⁴² F. Hajiesmaeilbaigi, H. Razzaghi, M. Mahdizadeh, M. R. A. Moghaddam, M. Ruzbehani, "Design and Construction of a 110W Green Laser for Medical Application," *Optics and Laser Technology*, Volume 43, Issue 8, November 2011, p. 1428-1430. See also F. Hajiesmaeilbaigi, H. Razzaghi, M. Mahdizadeh, M. R. A. Moghaddam, "High-Average-Power Diode-Side-Pumped Double Q-switched Nd:YAG Laser," *Laser Phys. Lett.*, Volume 4, N. 4, December 2006, pp. 261-264, Solid State Lasers Division, Laser Research Center, P.O. Box 14155-1339, Tehran, Iran.

⁴³ F. Hajiesmaeilbaigi, H. Razzaghi, M. M. Esfahani, M. R. A. Moghaddam, J. Sabbaghzadeh, "Experimental Study of a High-Power CW Diode-Sidepumped Nd:YAG Rod Laser," *Laser Physics Letters*, Volume 2, Issue 9, September 2005, pp. 437-439. The affiliation is given as the Solid State Lasers Division, Laser Research Center, P.O. Box 14155-1339, Tehran, although it is unclear if this affiliation refers to all the authors besides Hajiesmaeilbaigi. The P.O. Box is used by several groups in the AEOI, including the Nuclear Science

ISIS did not find many recent publications on copper vapor lasers or dye lasers. However, according to a web page of the AEOI, the Laser and Optics Research School developed the design and fabrication technology for copper vapor lasers. This web site page does not currently exist, but ISIS was able to retrieve it. However, the only two retrievable links date back to August and October 2011.⁴⁴

Ascertaining these centers' most recent activities is difficult. Several months ago, the web site of the INLC was removed. The reason for the web site's removal is not known. But the absence of the web site raises questions about the INLC's current activities.

The Nd:YAG lasers in these scientific publications also have specifications that would make them controlled under Nuclear Supplier Group (NSG) guidelines.⁴⁵ As such, Iran may become a supplier to states that cannot ordinarily import such lasers from suppliers in the NSG. Given the many Iranian statements about its commitment to spread advanced technology abroad, Iran could decide to sell such lasers overseas.

Iran's laser technology developed for non-nuclear purposes has the potential to be applied to uranium enrichment purposes either at a secret or declared site. As discussed above, Iran could conduct several necessary research and development activities for laser enrichment under a non-nuclear cover. Thus, Iran's work on lasers, some of which appear suitable for a laser enrichment program, have led to increased questions and concern about Iran's activities among a variety of nations and experts.

IAEA Concerns Justified

Iran has taken many actions that have compounded suspicions that it has not stopped its laser uranium enrichment activities. They include Iran's development of advanced lasers suitable for uranium enrichment, its past secret laser enrichment program, the extensive construction at Lashkar Ab'ad, and the 2010 high-profile announcement about having a uranium laser enrichment capability. As a result, the IAEA is justified to continue pursuing an investigation of whether Iran has had undeclared uranium enrichment activities since 2003.

To date, Iran has not provided the IAEA the requested additional information related to its February 2010 announcement and its advancements in relevant laser technology. The IAEA has also sought access to sites that could be involved in laser enrichment of uranium. For example, in a letter to Iran dated August 18, 2010, the IAEA repeated its previous request that Iran provide access to additional locations, including "research and development on uranium enrichment (including laser enrichment)."⁴⁶ Iran did not provide the IAEA with the requested information but reiterated that it was "continuing to cooperate with the Agency in accordance with its Safeguards Agreement."⁴⁷ The implication is that Iran believes it does not need to address the IAEA's concerns. That view is incorrect.

and Technology Institute, implying that the Laser Research Center given in this publication is the one under the NSTI and not Paya Partov.

⁴⁴Laser and Optics Research Center, AEOI Website Page, <http://web.archive.org/web/20111004130206/http://www.aeoi.org.ir/portal/File/ShowFile.aspx?ID=aeb5d6e6-df48-42fd-a8b5-d8868e75a18f>

⁴⁵ They would be under the NSG Dual Use List, topic 3.A.2.c.2.

⁴⁶ *Implementation of NPT Safeguards*, September 6, 2010, op. cit. p. 5, par 18.

⁴⁷ *Implementation of the NPT Safeguards*, September 6, 2010, op. cit. p. 5, par 18.

One issue is whether Iran is building a secret laser enrichment facility today or has decided to build one in the next few years. Iran would argue that based on its interpretation that its actions are governed by the original code 3.1 of its safeguards agreement, and not its modified version, it needs to provide design information six months before nuclear material is introduced at such a facility. However, the IAEA has determined that Iran must comply with the modified code 3.1, and thus must provide information about a facility prior to the start of construction or when construction is authorized. After receiving the information, then the IAEA would conduct Design Information Verification visits.

Given the evidence, Iran may have conducted since 2003 undeclared laser enrichment activities in violation of its safeguards agreement. In this case, the IAEA would have questions about whether all nuclear material in Iran is indeed declared, or alternatively, whether Iran's declaration is incomplete. Its requests to Iran aimed at resolving these concerns and questions follow legitimately from its mandate to enforce the comprehensive safeguards agreement.

Additional Sanctions, Expanded Controls

Absent Iranian cooperation with the IAEA that can clarify the situation, several additional measures should be implemented. These actions aim to make it more difficult for Iran to pursue laser uranium enrichment programs.

Additional sanctions designations are warranted. The Iranian National Center for Laser Science and Technology and the Laser and Optics Research School should be designated for sanctions by the United States, the European Union, and Japan. In addition, key personnel should also be designated. At a minimum, Jamshid Sabbaghzadeh should be sanctioned. In addition, sanctions of these entities and individuals should be sought under U.N. Security Council sanctions.

The IAEA should also amend Annexes 1 and 2 of the Additional Protocol with respect to lasers. These annexes define what is contained in a state's declaration and is subject to state export and import reporting.⁴⁸ For example, this annex does not list all the lasers now subject to controls. Annex 2, which is based on revision 2 of the Part 1 list of INFCIRC/254 and dates to 1995, reflecting laser systems used then. In amending Annex 2 and Annex 1, the IAEA should aim to subject the manufacturing of key lasers to greater scrutiny.

Countries should apply a higher priority to detecting any Iranian procurements of laser enrichment related technology, equipment, and materials, including subcomponents of advanced lasers. This action would be justified under "catch all" clauses in export controls, which aim to keep goods out of unsafeguarded, sanctioned, or otherwise suspect programs. It also makes sense to add additional laser related equipment and subcomponents to "watch lists" for laser enrichment. In this context a watch list refers to a list of critical goods used in a laser enrichment program that would serve as a guide to suppliers or governments of the most important goods to monitor for export with the goal of preventing sales, identifying smuggling networks, and learning more about covert or sensitive nuclear programs. A good on a specific watch list may or may not be on a dual-use control list, such as the Nuclear Suppliers Group dual-use control list, INFCIRC/254/PART 2; in fact, the watch list is not a control list. If a good on a watch list is not on a corresponding control list, it is on the watch list typically because proliferant states have often sought this item for one of their nuclear programs. For example, a thyratron is not on such a list but it would be a good candidate to add to a laser

⁴⁸ Under Article 16 of the Additional Protocol, the list of activities specified in Annex I, and the list of equipment and material specified in Annex II, may be amended by the Board upon the advice of an open-ended working group of experts established by the Board. Any such amendment shall take effect four months after its adoption by the Board.

enrichment watch list. The NSG should also evaluate such key subcomponents with an eye toward including them on the dual-use control list.

Final Word

Concerns about Iran's possible laser enrichment efforts are not as pressing as those focused on its gas centrifuge and heavy water reactor efforts, both of which are much further along in their potential for providing Iran with the capability to make the nuclear explosive materials highly enriched uranium and separated plutonium. However, questions about Iran's laser enrichment activities should be resolved. Moreover, concerns about alternative enrichment programs reinforce the need for Iran to ratify the Additional Protocol and accept additional verification measures as soon as possible to ensure that Iran, a known multiple violator of its safeguards agreements, is not pursuing secret, undeclared nuclear activities.