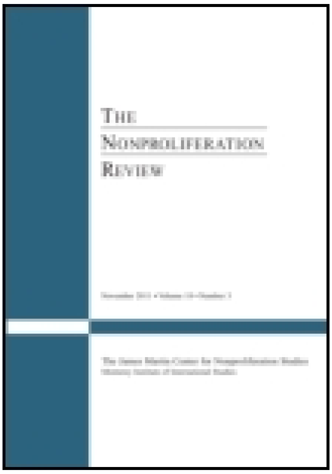

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In the spring of 1975, Iran became one of the first states to begin comprehensive research into using lasers for uranium isotope separation. As part of that research, the government sought the expertise of Jeff Eerkens, a leading American specialist in the field. This investigative article tells the story of their relationship: how it began, how it developed, and how it ended, drawing extensively from the authors' personal interviews with Eerkens as well as numerous publications and other interviews.

KEYWORDS: Iran; United States; uranium; laser enrichment; Jeff Eerkens

When the laser was invented in the 1960s, research immediately began into its possible military and civilian applications.[1] First came pulsed lasers, which relied on an artificially grown ruby crystal as the active element; gas-discharge tubes were used for pumping excitation. Numerous other types of lasers were developed in later years, including gas lasers (which use inert gases, metal vapor, carbon dioxide, etc.). One of the first areas of research into commercial application of lasers was uranium enrichment. In the Soviet Union, this research began in 1967 at the Kurchatov Atomic Energy Institute (now known as the Kurchatov Institute).[2] In the United States, Lawrence Livermore National Laboratory (LLNL) was the first to start using lasers to separate uranium isotopes in the early 1970s.[3] In France, a similar project started in the early 1980s.

Iran's Laser Enrichment Program: The First Steps

Iran began to explore the possible uses of lasers in the early 1960s.[4] It launched an ambitious nuclear energy program in 1974 and was one of the first countries to begin comprehensive research into using lasers for uranium isotope separation. In the spring of 1975, the Laser Technology Division at the Tehran Nuclear Research Center (TNRC) was established. The division was to be given a newly built 1,000 square foot research facility.[5] The plan was to explore the technology of atomic vapor laser isotope separation (AVLIS) and molecular laser isotope separation (MLIS). As part of the AVLIS project, in 1975 the Atomic Energy Organization of Iran (AEOI) signed a contract with a West German company to establish a laboratory to study the spectroscopic behavior of uranium metal.[6] An order for some of the equipment for the laboratory was placed with Britain's Lintott Engineering

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Limited.[7] Speaking at an international conference on the transfer of nuclear technologies held in April 1977 in Persepolis and Shiraz, Iranian scientists reported that they had independently developed and manufactured carbon dioxide lasers with an output of 6 watts (W).

Because Iran intended to develop a molecular laser isotope separation technology, which uses uranium hexafluoride in the process, the AEOI reached an agreement with South Africa to buy the technology to produce uranium hexafluoride.[8] Under the plans approved by Shah Mohammad Reza Pahlavi, Iran was to have 23 gigawatts of nuclear energy generation capacity by 1994. In order to satisfy the projected demand of its future nuclear energy industry, in 1975 Iran acquired a 15 percent stake in the Rossing uranium mine in South Africa (territory that is now part of Namibia).[9]

The TNRC hired its first four laser specialists—two Iranians, an Israeli, and an American—in the second half of 1975.[10] In 1977, the TNRC Laser Technology Division had five physicists with a PhD degree, four with a Master's degree, six undergraduate students and four technicians.[11] Several of the Iranians working at the division were graduates of the Massachusetts Institute of Technology.[12] The division projected a future staffing requirement of twenty or more individuals a year. These positions were to be filled by inviting Iranian specialists working abroad, training specialists at the center's own laboratories, and inviting the leading scientists from other countries, including the United Kingdom, Germany, and the United States.[13] Tehran also set up a special scholarship program for Iranian laser specialists wishing to continue their education abroad and earn a PhD degree from the leading foreign universities, on the condition that those specialists return to Iran and continue to work in the laser field once they completed their studies.[14] For example, Iranian specialists studied at Heriot-Watt University in Edinburgh, one of the largest in the United Kingdom.[15]

As part of its research into molecular laser separation of uranium isotopes, TNRC relied on cooperation with Jeff Eerkens, a leading American specialist in the field. This article tells the story of how that cooperation began, how it developed, and how it ended. It is based on numerous publications and interviews, drawing heavily on the author's personal interviews with Eerkens.

Jeff Eerkens: From Berkeley Student To Laser Luminary

During the 1960s and 1970s, the US government made research into the various applications of lasers an important priority. Jeff Eerkens, an American of Dutch descent, was one of the first American scientists to begin to study the possibility of using lasers for separating the isotopes of heavy elements. He was born Jozef W. Eerkens in 1931 in Indonesia, a Dutch colony at the time, where his father was a physician. In 1950, Eerkens came to the United States to enroll at the newly created Nuclear Engineering Department of the University of California, Berkeley. He graduated in 1957; three years later, he received his PhD degree in engineering.[16] His PhD thesis focused on studying various chemical effects in fluids produced by uranium fission fragments.

Eerkens's interest in nuclear engineering largely stemmed from his childhood experiences. During World War II, he spent three years in a Japanese concentration camp on Java, from which he was freed only after Japan capitulated. He believes that the use of nuclear weapons by the United States in Hiroshima and Nagasaki saved his life, and later fuelled his interest in nuclear engineering, which became a central focus of his career.[17]

He received his first job as a nuclear scientist in 1957, while completing his Master's program. He worked at the Engineering Field Station of the University of California-Berkeley, where he measured the efficiency of the separation of uranium isotopes using a variant of an enrichment technology developed by German physicist E.W. Becker (the so-called nozzle separation method).[18] The project was commissioned by the US Atomic Energy Commission (AEC).

During his PhD studies in 1957–60, Eerkens worked as a nuclear reactor engineer and physicist-in-charge for Aerojet-General-Nucleonics (AGN). He received a license to operate the AGN-201 and AGN-211 research reactors and helped install these units for AGN at the University of Oklahoma (Norman, Oklahoma) and Rice University (Houston, Texas). As part of his work for AGN, he also took part in designing mobile land-based and spaceborne nuclear reactors (as part of the Systems for Nuclear Auxiliary Power, or SNAP project, and the Space Power Unit Reactor project). In 1961, he became a US citizen, which increased his opportunities to participate in classified projects commissioned by the US government.[19]

After completing his PhD studies, Eerkens settled in California, where he worked for several leading American aerospace companies. In 1960, he joined Aerospace Corporation, where he specialized in nuclear rocket propulsion studies and was involved in space surveillance satellite programs. These programs included the development of the VELA family of satellites, designed specifically to monitor the Soviet Union's compliance with the Limited Test Ban Treaty signed in Moscow on August 5, 1963. Eerkens also participated in the Missile Defense Alarm System and the Satellite and Missile Observation System programs.

In 1963, Eerkens joined the Northrop Space Laboratories (NSL), where, for the first time, he became involved in laser-related projects, becoming the chief of the laser systems branch.[20] In just one year, he managed to design, build, and demonstrate the world's first working direct nuclear-pumped gas laser, powered by the TRIGA (Training, Research, Isotopes, General Atomics) pulsed reactor.[21] But as a result of the growing costs of the war in Vietnam after a full-scale American intervention in the conflict in 1964, the US government had to cut spending on defense research projects, including space projects. In 1967, Northrop was forced to shut down NSL. Eerkens and several of his colleagues were asked to join the electronics division within the company, which would have meant abandoning their laser research.

Instead they decided to leave Northrop and to set up a new company, Xion, specializing in designing, manufacturing, and selling lasers. But finding customers proved very difficult. After six months, the partners decided to shut down their company and become salaried employees once again.

In 1967, Eerkens's previous boss at Northrop, N.K. Satyendra, an American scientist of Indian descent who had previously served as vice president of NSL, learned that Eerkens was once again looking for a job and invited him to join his newly created company, Science and Technology Associates (S&T). S&T was set up after the closure of NSL; its main customer was the Department of Defense. Eerkens was therefore able to continue his laser research at the new company. One of the projects involved analyzing the plumes of Soviet ballistic missiles and identifying the composition of their fuel by spectral measurements from satellites. He also explored the possibility of using lasers to probe rocket exhaust plumes and to propel balloons on US reconnaissance missions over a Chinese missile testing range. It was during his time at S&T, in 1969, that Eerkens, who was looking into potential new applications for lasers, first thought of the possibility of using lasers to separate uranium isotopes, and made his first theoretical calculations.[22] He focused on the molecular method of laser isotope separation of heavy elements, now known as MLIS; he believed that the method would be easier and cheaper to implement because, unlike the atomic vapor laser isotope separation (AVLIS) technology, it did not involve hard-to-handle substances such as metallic uranium vapor. During his time with S&T, Eerkens also initiated his first uranium laser enrichment patent applications.

A talented scientist and author of numerous research papers, Satyendra proved less successful as a businessman. By the late 1960s, his company was on the verge of bankruptcy. He had to lay off workers, retaining only two employees (including Eerkens) to complete the existing contracts. But Eerkens was forced to leave the company in 1970 after Satyendra—already depressed over his business woes—killed himself a few months after his wife filed for divorce.

Laser Enrichment: Eerkens's First Success

In April 1971, with the help of a recommendation from an S&T lawyer, Eerkens got a job with AiResearch Manufacturing Co., a division of Garrett Corporation, which was one of America's leading aerospace companies. In the early 1960s, several US national laboratories and industrial corporations received contracts from the AEC to develop gas centrifuge enrichment technology suitable for commercial-scale application. Garrett began developing such centrifuges as part of a classified project in 1961.[23] Eerkens was hired as a staff scientist to work on the gas centrifuge project for uranium enrichment and to explore laser enrichment.[24] While at Garrett, he was also responsible for completing the *Rocket Radiation Handbook*, a project commissioned by the US Air Force that he started during his time in S&T.[25]

Eerkens shared his ideas about the potential of the molecular technology of laser separation with the top Garrett management; he lobbied for funding to be allocated to put these theories to the test. The AiResearch gas centrifuge program already involved two of the main components required by the experiments proposed by Eerkens: uranium hexafluoride and mass spectrometers, which were used to measure the level of uranium enrichment. The funding Eerkens was requesting was therefore quite modest; the only expensive part was to design and manufacture the actual lasers. The company approved his proposals and Eerkens was appointed manager of the laser enrichment project, while at the same time continuing his work on the gas centrifuge. He also secured an agreement with the company to share the rights to any inventions made in the process.

In 1972–73, Eerkens built and operated an experimental laser enrichment unit, which he used to investigate isotope-selective laser enhancement of slow chemical reactions in gaseous mixtures of uranium hexafluoride and hydrogen chloride. In his experiments, Eerkens used a carbon dioxide laser of his own design, with a wavelength of 10 microns. The results he obtained were validated by Garrett mass spectrometry specialists; their measurements indicated that Eerkens had achieved a separation factor of 1.01.[26] That was better than the 1.004 factor of gaseous diffusion technology, which was the prevailing enrichment method at the time.[27] The experiment was repeated several times, delivering consistent results.[28] Eerkens believed that the technology could be further improved to achieve a separation factor of 1.1–1.5. By way of comparison, the IR-1 gas centrifuge—which currently forms the core of Iran's nuclear enrichment capability—has a separation factor of about 1.3.[29]

Citing these results, Garrett Corporation applied to the AEC for funding. The application was passed on for technological vetting to the Los Alamos National Laboratory (LANL), which was the lead US organization for the research of molecular laser isotope separation. Los Alamos specialists concluded, however, that the proposed uranium enrichment technology was not viable. Based on that conclusion, AEC denied funding for further research. For the same reason, they decided that there was no reason to classify the technology.[30] It is most likely, however, that, since the laboratory responsible for assessing Eerkens's technology proposed was simultaneously receiving generous government funding for the research on the molecular laser separation method, there was a conflict of interest: LANL probably saw Eerkens's technology as a competitor to its own research.[31]

Nevertheless, AiResearch continued to fund Eerkens's experiments from its own budget. Several months later, it submitted another funding application to the AEC, but the request was also denied. The AEC recommended that Garrett stick to developing the gas centrifuge technology, a project it was already funding. In late 1975–76, AiResearch decided to discontinue its laser enrichment efforts. One reason was the company's unwillingness to plow its own money into a project directly competing with a similar program at LANL, especially since the work of its rivals was being heavily funded by the government at the rate of up to $30 million a year.[32] In addition, differences broke out between Garrett's management and Eerkens over the timing and the size of royalties to be paid to him for the use of his patented technologies.

On December 11, 1975, Eerkens filed a second patent application for a laser-based method of separating the isotopes of heavy elements, which he called Laser ISOtope SEParation (LISOSEP).[33] The patent application contained a description of the separation technology and of a uranium enrichment plant using that technology. According to that description, the plant is capable of enriching natural uranium to the 2.5–7 percent level in a single cycle (which translates into a separation factor of 4–10). The estimated cost of separation using such a plant was said to be just 0.1–1 percent of the corresponding figure for a plant based on gaseous diffusion technology.[34] The figures stated in the patent application were obtained by theoretical calculations and had not been confirmed by experiments.[35]

Eerkens was unhappy with the way AiResearch handled the laser project. More specifically, he was concerned about the company's failure to secure extra funding for further research, the slow pace of the project, and the need to share his time between the gas centrifuge and the laser project. As a result, he began to look for other parties that might be interested in exploring the use of laser enrichment technology.[36]

The Letter To The Shah Of Iran

Eerkens undertook energetic efforts to spread the word about his laser research. On January 2, 1976 he submitted an article describing his experiments at AiResearch and the results he had achieved to the journal *Applied Physics B: Lasers and Optics*. The article was accepted and published May 1976.[37] In June 1976, Eerkens delivered a report at an international conference on quantum electronics in Amsterdam. Shortly afterwards, he held a presentation at the Saclay Nuclear Research Centre in France.[38]

In an effort to find customers and investors for his uranium enrichment technology, Eerkens investigated various new potential funding sources. Having failed to secure support and financing for his research from US companies and government agencies, Eerkens began to think about potential foreign investors. One of the first persons he contacted was a vice president of Royal Dutch Shell. Shell at that time was looking into diversifying its business. In 1974, it acquired a 50 percent stake in General Atomics.[39] But the European oil giant's specialists who arrived in San Diego, California, to discuss opportunities for cooperation showed no interest in Eerkens's technology.[40]

Don Watson, an entrepreneur from Florida and a friend of Eerkens, proposed seeking funding from Libyan ruler Muammar Gaddafi, who declared in the late 1970s that he was willing to spend up to $10 billion on developing nuclear technologies in his country.[41] But Eerkens rejected the idea.[42]

Then help arrived from unexpected quarters. In the early 1930s, Jan Boost, Eerkens's uncle, taught German and French to the Shah Mohammad Reza Pahlavi, when the latter studied at Institut Le Rosey, one of Switzerland's most prestigious boarding schools. Eerkens told that story to Iranian businessman Sassan Safa, who made a living by exporting American electronics to Iran. Safa immediately said that, given the role Eerkens's uncle had played in the education of Mohammad Reza Pehlavi, the scientist should apply of funding for his laser enrichment research to the Shah, who was known for his support of high-tech projects. Ted Farrell, a friend of Eerkens who was present at the conversation, expressed his doubts about the idea. He argued that the Shah had just given France a $1 billion loan to build a gaseous diffusion uranium enrichment plant as part of the Eurodif international consortium.[43] But the Iranian businessman said he would draft a letter to the Shah, which Eerkens signed and mailed on February 11, 1976.[44]

The letter—addressed to "His Imperial Majesty, the Shah of Iran, Tehran, Iran"—mentioned the LISOSEP laser enrichment technology developed by Eerkens.[45] It said that based on the experiments conducted in 1972–73, the technology promised to be much more economical than all the existing alternatives, including gas centrifuges. The letter argued that a commercial-scale uranium enrichment plant based on the laser technology would cost only $100 million, about one-twentieth of the cost of the plant based on the gaseous diffusion technology. Eerkens attached to the letter his resume and a list of his published papers to demonstrate his scientific credentials.

Eerkens did not have any great expectations from the letter, but two weeks later he received first a telegram and later a phone call from Mojtaba Taherzadeh, director of the TNRC. Thus Eerkens's career path became intertwined with the Iranian laser enrichment program.

Taherzadeh obtained a PhD from the University of California in 1964 and became a US citizen. He had spent a long time working for the American defense industry.[46] Prior to his return to Iran, he took part in a project to develop spaceborne nuclear reactors for the SNAP project at the Jet Propulsion Laboratory.[47] In an interesting coincidence, Eerkens had participated in the same project in the late 1950s when he was preparing his doctoral thesis and working for Aerojet-General-Nucleonics. Taherzadeh invited Eerkens to visit Tehran—with TNRC paying the costs—to discuss cooperation.

Jeff Eerkens's Iranian Project

Eerkens requested the consent of the Energy Research and Development Administration (ERDA), the successor of the AEC, to discuss the possibility of cooperation with the AEOI in implementing his laser enrichment technology. But the ERDA Division of Classification and the Office of Advanced Isotope Separation expressed serious proliferation concerns and voiced its objections (notwithstanding the fact that just a few years earlier, the AEC had declined to classify this technology). After consulting his lawyer, Eerkens withdrew his request for ERDA consent, since according to the legal advice he had received, he did not actually require any official approval to hold consultations in Tehran.[48]

In the fall of 1976, Eerkens took several days' leave at AiResearch to visit Tehran and discuss the terms of cooperation with Iranian scientists to develop further his LISOSEP uranium enrichment technology. Eerkens obtained the Iranian entry visa right at the Tehran airport after informing the border officials that he had been invited to the country by the AEOI.[49] After passing all the border and customs formalities, he was met at the airport by TNRC Director Taherzadeh.

During that visit to Tehran, Eerkens held talks with senior Iranian nuclear officials, including AEOI President Akbar Etemad, Taherzadeh, and TNRC Laser Technology Division Chief Ehsanollah Ziai, who later became one of Eerkens's main negotiating partners.[50] The vast majority of the scientists who took part in the meetings were US-educated and spoke fluent English, so there was no language barrier. Dr. Ziai was educated at the University of Southern California, but returned to Iran and joined the TNRC when the Shah announced the launch of an ambitious nuclear program. During his stay in Tehran, Eerkens also visited the Iranian nuclear research facilities and met TNRC scientists. In particular, he was given a tour of the TNRC laboratories and TRIGA research reactor. He was impressed by the rapidly growing Iranian capital, with its bustling construction sites and new office centers hosting the local branches of transnational corporations. At the invitation of one of the TNRC staff members, Eerkens attended a Tehran Opera performance at the Rudaki concert hall, and was greatly impressed by what he saw.[51]

One of the main outcomes of Eerkens's visit to Tehran was the AEOI's subsequent consent to finance further research into LISOSEP laser enrichment technology and an agreement to build a laser enrichment laboratory based on that technology at the TNRC Laser Technologies Division. The plan was that all further research would be conducted simultaneously in Iran and the United States, and that a total of six experimental laser enrichment units would be made, each consisting of the laser, the ancillary optical equipment and the irradiation chamber. Four of those units were to be delivered to the TNRC and two installed at a facility in California, near where Eerkens was living. According to Eerkens's calculations at that time (which had not been experimentally tested prior to the signing of the contract with the Iranians), each of the four lasers was capable of producing up to 1 kilogram (kg) of uranium enriched to 5 percent every day, using natural uranium (which has 0.71 percent uranium-235 content) as the source material.[52] Eerkens believed that having a similarly equipped laboratory in the United States would make it easier to obtain the high-tech hardware needed for the project.

The priority for TNRC was to improve the LISOSEP technology in order to explore its possible uses in the future on an industrial scale. The tentative plan for the longer term was to build an enrichment facility using the new method of producing low-enriched uranium for nuclear fuel in addition to the separation capacity of the gaseous diffusion enrichment plant in Tricastin (France), in which Iran held a 10 percent stake.[53] A report released in June 1977 by the Congressional Office of Technology Assessment said that at some point in the future, Iran could potentially become an exporter of uranium enrichment services.[54]

Upon his return to California, Eerkens told his bosses at AiResearch about the outcome of the talks in Tehran. He invited the company to join the implementation of the agreements reached with the Iranians, which would enable him to use the existing infrastructure and hardware at AiResearch. But the company's bosses rejected the proposal and were unhappy with the very idea of Eerkens holding the talks in Iran. They declined the AEOI's offer of financing for further research into laser enrichment. But, according to a conclusion made in 1980 by the General Accounting Office (GAO, the investigative arm of Congress), Eerkens had not broken any US laws by visiting Tehran and holding talks with the AEOI.[55]

After his proposals were rejected by AiResearch, Eerkens once again became convinced that there was no alternative but to establish his own company. On November 24, 1976, he and his colleague, Titus Nelson, who was interested in making lasers for consumer applications (mainly for laser engraving), registered the Lischem Company in Miami, Florida. The name Lischem stood for Laser Isotope Separation and Chemistry.[56] The company had a small industrial building in Lawndale, California, near the Los Angeles International Airport and only a few miles from the offices of AiResearch, where Eerkens continued to work until April 1977. The money to set up Lischem was raised with the help of Don Watson, the aforementioned entrepreneur from Florida. Watson agreed to invest his own money and found six additional private investors in Florida willing to contribute a total of $50,000 in return for a stake in the new company.[57] By October 1976, Eerkens had assembled a group of six scientists and engineers, most of whom had previously worked with him. Several weeks later, they were officially hired by Lischem and became the company's first employees.

In the spring and summer of 1977, Eerkens and TNRC director Taherzadeh had two meetings in Los Angeles, not far from where Eerkens lived, to discuss the details of the project to build a laser enrichment laboratory in Iran. During the meetings, the two sides reached an agreement, in principle, on three main areas. First, they agreed that the project would be implemented in two phases. The first phase was to include the manufacture and delivery to Iran of the necessary equipment: four carbon monoxide lasers (LCL-516 model, 25W), and four irradiation chambers (LCR-350 model). The agreed specifications of the experimental laser enrichment unit included irradiation chambers made of nickel, a corrosion-resistant material, to make sure that the chamber could work with halogen gases, and a special design enabling it to be easily disassembled if the need arose.[58] During the second phase of the project, Eerkens was to travel to Tehran and bring with him the optical equipment for the laser enrichment laboratory (which was small enough to fit into carry-on luggage). He was to provide technical assistance during the installation and launch of the equipment, and during the first two years of its operation. The plan was for Eerkens to move to Iran and to bring his family with him.[59] The overall value of the contract was $2.35 million, of which hardware accounted for $630,000.[60] The cost of the services and equipment was based on figures from the Lischem product catalog.

The second agreement, which was proposed by Taherzadeh, was that the equipment for the laser enrichment laboratory would be supplied to Iran via Gifted, Inc., which would act as Lischem's export agent. Gifted was founded by Naim Perry, a US-Iranian businessman. Perry was making most of his money on real estate investment; he was the president of Properties Management and Diversified Development, Inc. He and his wife were also the co-founders of Gifted, Inc., which specialized in exports and imports of high-tech products. Perry had already had some business dealings with the AEOI, and, unlike Eerkens, he had already had a lot of experience in obtaining US export licenses for high-tech equipment.[61]

One of the terms of the deal on which Perry had insisted was that he should be allowed to be the only capital investor in Lischem. All existing shareholders agreed to sell their stakes at a 10 percent premium less than a year after making the original investment. Lischem was then re-registered in California in July 1977. Naim Perry received full control over the company's finances.

Under the agreement reached with the Iranians, the AEOI was to pay Gifted directly for all the equipment to be supplied to Iran. Commercial dealings between the two sides were based on pro forma invoice No. 4080 of July 6, 1977, submitted by the US company to the AEOI, and irrevocable letter of credit No. 08/92282 of November 15, 1977, issued by the Iranian central bank (Bank Markazi) at the request of the AEOI.[62] Gifted then signed a subcontract with Lischem to produce the required equipment. Later, there were two addendums to the letter of credit. Under the first addendum, the expiration date of the letter was extended until November 15, 1978. Under the second, the equipment was to be supplied in two batches (two sets of equipment in the first batch and another two in the second batch).[63]

The third area of agreement concerned the specifications for the lasers. The Iranian side was interested in buying lasers with a wavelength of 16 microns, which are ideally suited for use in uranium enrichment. Under the terms of the preliminary agreement reached in Tehran, such lasers were to be supplied.[64] But Eerkens was forced to admit that he did not have the technology to make lasers of that wavelength. That is why he proposed—and the Iranians accepted—that to obtain the required system specifications, they would use 25W carbon monoxide lasers with a wavelength of 5 microns, coupled with a carbon tetrafluoride wave length converter. The combination produced the required laser radiation with a wavelength of 16 microns, to achieve the optimum efficiency of the enrichment process.[65] The lasers were of "flexible design," i.e., the carbon monoxide they used as the active material could be replaced with another gas, thereby changing the properties of the laser.[66]

Eerkens made another visit to Tehran in early 1978 in order to discuss the final details of his work at the TNRC as part of providing assistance in the installation and operation of the experimental laser enrichment units. He also needed to arrange his and his family's relocation to Tehran, including housing and the selection of an international school for his children.[67]

Licensing The Export of Laser Equipment To Iran

On February 7, 1978, Gifted applied to the Department of Commerce (DOC) for a license to export four lasers and related equipment to Iran. In accordance with US laws, the application contained information about the intended use of the equipment to be supplied, which was stated as "laboratory plasma research." The equipment to be exported, i.e. the experimental laser enrichment units, relied on technology which was not classified by the Department of Energy (DOE), ERDA's successor, so the company decided to declare a broader scope of its application to simplify the procedure and expedite the licensing process. The application did not specify that the intended use of the equipment to be exported was to enrich uranium.[68] This made for a simpler procedure for the review of the application, bypassing the more intrusive aspects of it and the need for personal vetting by the Secretary of Energy (James Schlesinger at the time). The application also did not state the power output of the lasers to be supplied.[69]

Just when the application was being processed, the US Congress passed the 1978 Nuclear Nonproliferation Act (NNPA), which tightened controls over the exports of technologies that could potentially be used for building nuclear weapons.[70] In accordance with the new law, if the DOC and the DOE believed that that the application for export license should be denied or reviewed further, they were to submit that application for the consideration of a special interagency group. The group included representatives of the Department of State, the Department of Defense, the DOE and the DOC, the Arms Control and Disarmament Agency, and the Nuclear Regulatory Commission.

Following the new procedure, the application filed by Gifted was passed on to the DOE. After reviewing the application, on February 14 a DOE expert instructed the Department of Commerce not to issue the license for the time being, and to submit the application to the DOE for closer scrutiny. According to the expert, he made the decision after becoming suspicious about the unusually high price of the equipment stated in the application.[71]

On March 17, 1978, the DOE sent the application for technical review to three DOE-related organizations: the DOE Office of Laser Fusion, the DOE Office of Advanced Systems and Materials Production, and LLNL, which was researching AVLIS technology at the time. The DOE decided not to ask experts from LANL, which was the lead US organization for MLIS technology, and which had already conducted an assessment of the laser enrichment technology developed by Eerkens when he worked for Garrett Corporation. On March 23 and April 5, the first two organizations informed the DOE that they had no objections to the export license application. LLNL requested additional technical information about the lasers to be exported; the laboratory's experts believed that such information should have been provided in the original application. There is no definitive information about the final conclusion made at Livermore. According to DOE officials, the response from the laboratory said there were no reasons to reject the export license application, but these officials could not provide any documentary evidence of the laboratory's finding. Meanwhile, LLNL representatives said they never issued any official conclusion on the matter because they had received incomplete technical information about the equipment to be exported.[72]

On June 13, 1978, based on the conclusions made by its specialists, the DOE returned to the DOC a recommendation that the requested export license should be granted because the equipment to be exported posed no nuclear proliferation risk. On June 20, Gifted received a DOC license to export to Iran the four lasers and related equipment for use in laboratory plasma research.[73]

In researching this article, I have failed to identify a definitive answer to the question of why the export license application was approved, even though DOE officials had previously objected to Eerkens's discussing the project with the AEOI and expressed serious proliferation concerns at that time. The explanation probably includes a variety of factors, including commercial, political, technological, and bureaucratic. Imperfections in the export licensing process also seem to have played a role.

The United States and Iran spent several years in difficult talks on an agreement on peaceful nuclear energy cooperation (the so-called 123 Agreement) before the document was finally initialed on July 10, 1978.[74] One of the most contentious issues during the consultations was the development of sensitive elements of the nuclear fuel cycle on Iranian territory. The US nuclear industry had pinned great hopes on the large Iranian market. It also saw Iran as a potential source of significant investment, including in projects to build new uranium enrichment facilities.[75] For example, Westinghouse hoped that Washington would help US companies win 75 percent of the world market for exports of nuclear power plants by 1982.[76] The company had plans to build six to eight power reactors in Iran.[77] On June 30, 1974, the AEOI and the AEC signed two preliminary contracts for the supply of nuclear fuel.[78] In that context, a refusal to grant a license for export of laser equipment to Iran of could adversely affect the progress of the talks and the commercial prospects of US companies in the Iranian market, where Germany's Siemens and France's Framatom were already present. Some US government experts viewed supplying sensitive American materials and technologies to Iran, including highly enriched uranium (HEU), as a way of strengthening the US reputation as a reliable nuclear exporter and of encouraging Iran to choose US companies for multibillion dollar contracts to build nuclear power plants in the country.[79]

Also, amid the increasingly tense domestic political situation in Iran and a growing wave of protests against the rule of the Shah, who was viewed by Washington as a key ally in the Gulf region, it was important for President Jimmy Carter's administration to demonstrate its staunch support for Mohammad Reza Pahlavi and his regime. The last thing Washington wanted was to undermine the already weak rule of the Iranian monarch.[80] A refusal to issue the export license—had it been leaked to the media—would have been seen by the supporters and the opponents of the Iranian regime as a sign that the White House was abandoning the Shah, and that America was ready to work with the opposition forces. After turmoil began to rock Iran, Washington took this consideration into account when deciding whether to remove more than 5 kg of 93 percent enriched uranium of US origin from the Tehran Research Reactor.[81]

It is also likely that the decision to issue the export license was influenced by Washington's skepticism about the usability of the laser technology for uranium enrichment. In 1973–74, the AEC decided there was no reason to classify the information about Eerkens's first experiments and achievements in molecular laser enrichment made when he was working for AiResearch. In the late 1990s, when new reports appeared about Iran's intention to buy laser equipment suitable for use in uranium enrichment, most US scientists spoke condescendingly about the Iranians' interest in that technology. They thought it a waste of time, and viewed laser enrichment as a technological dead end.[82]

Also, according to a report released by the GAO on March 17, 1980, the DOE's examination of the export license application filed by Gifted, Inc. was not sufficiently comprehensive. GAO found that the DOE failed to request the necessary additional information from the applicant, including data about the power output of the lasers to be exported, and that it did not contact the manufacturer, Lischem, for details about the intended use of the equipment.[83] In addition, the DOE's recommendation to the DOC to issue the export license to Gifted, Inc. appears to have been made before the DOE had received the conclusions of LLNL, which had been asked to conduct technical analysis of the export license application. Neither did the decision to issue the license involve specialists at LANL, which was the lead organization for the research of molecular laser enrichment. Finally, the DOE had failed to establish that the founder of Lischem, Jeff Eerkens, had previously been involved in classified US government programs to develop the gas centrifuge technology of uranium enrichment.[84]

Turmoil In Iran: Delivery Of The Laser Equipment

The economic and domestic political situation in Iran had changed greatly in the period between Eerkens's visit to Tehran in early 1978 and the moment in June 1978 when Gifted, Inc. received its export license.

The country was confronting a spiraling political and economic crisis. Ordinary Iranians, who regarded Iranian oil as their national wealth, did not see any changes for the better in their lives even as Iran's oil export revenues were growing at a rapid pace.[85] There was pervasive corruption, which affected even the top tiers of the government, and growing discontent with the ruling regime. Most Iranians wanted radical changes. In 1978, amid growing inflation, falling real incomes, and widespread discontent over the government's social policies, the country plunged into turmoil. In May-June 1978, the first open protests erupted against the Shah's regime, which quickly degenerated into rioting in Tehran and other major cities.[86] On September 8, the government declared martial law in Tehran and eleven other cities. It sent tanks to the capital's international airport to bolster its security and protect critical infrastructure. Mass anti-Shah protests paralyzed the entire country in September-October 1978.[87] On January 16, 1979, Shah Mohammad Reza Pahlavi gave up his attempts to cling to power and left the country.[88]

The year before the fall of the Shah's regime, the Iranian government, facing a massive budget deficit, was forced to review its energy diversification program. It declared a moratorium on signing new contracts for the construction of nuclear power plants.[89] Soon afterwards, it cancelled several nuclear projects for which it had already signed contracts. In late 1978, it froze the construction of the Esfahan Nuclear Technology Center, which was being built with the assistance of French specialists. In January 1979, Iran canceled the contract for the construction of nuclear reactors in Darkhovin with France's Framatome, citing lack of financial resources. In July 1979 Germany's Siemens suspended construction at the site of the Bushehr nuclear power plant after Iran ran up large debts for the work which had already been delivered. In September 1978, AEOI President Akbar Etemad quit his job, and the organization lost its independent status, becoming a division of the Ministry of Energy.[90] On November 8, Amir Abbas Hoveyda, who had served as the Iranian prime minister for many years and who was one of the main proponents of nuclear energy in the Iranian government, was arrested.[91]

In July 1978, the Iranian desk at the State Department concluded that the fall of the Shah's government in Iran was inevitable. In October 1978, State decided to establish contacts with Ayatollah Ruhollah Khomeini and his supporters in Paris. Nevertheless, some senior US officials, including National Security Advisor Zbigniew Brzezinski, continued to consider possible ways of perpetuating the Shah's regime well into December.[92]

Shortly after Gifted, Inc. had received the export license in June 1978, the company informed the AEOI that the equipment was ready to be shipped. It asked Iran to send two specialists to the United States to certify the lasers, as previously agreed. But by that time the AEOI had already lost interest in the laser enrichment laboratory. Iran instructed Gifted, Inc. not to supply the equipment.[93] In order to formally discharge its contractual obligations and recoup the money invested in making the hardware, the US company invited an independent expert, an electrical engineering professor from the University of Southern California, to rate the output of the lasers it had made. The expert's measurements put the output of the lasers at 26W (under the agreement, the figure should have been at least 25W).[94] The equipment was then shipped to Iran on November 8, the day when former Iranian Prime Minister Hoveyda was taken into custody, and a week before the expiry of the letter of credit issued by the Iranian central bank at the request of the AEOI. [95] The equipment included two lasers and two irradiation chambers. It was packaged into eight crates weighing over 3 tons, and sent to Tehran on an Iran Air flight.[96] Another two sets were shipped to Iran later.[97]

The original plan was to make six sets of the equipment. However, Lischem manufactured only "five and a half" sets—namely, five laser systems and six irradiation chambers. Four of these sets were supplied to Iran; the remaining laser and two chambers were later installed in a Lischem workshop in California.[98]

After mass protests broke out in Iran, the State Department issued a warning that it was no longer safe for Americans to travel to the country. Eerkens and his family were in the Netherlands at that time, waiting for the situation in Iran to return to normalcy. He had with him the optical equipment for the experimental laser enrichment units. Eerkens spent more than four months waiting, but after the Shah left Iran, he was forced to return to California. The new Iranian leadership showed no interest in continuing the nuclear projects launched under the Shah. Eerkens unsuccessfully tried to contact Taherzadeh to find out what had happened to the equipment already sent to Tehran. But the former TNRC chief had already left Iran; he fled to the United States by way of Turkey. The former AEOI president, Akbar Etemad, emigrated to France.[99]

The Iran–United States Claims Tribunal: The Laser Affair

After the equipment was shipped to Iran, Gifted attempted to claim payment; the company believed that it had fulfilled its obligations under the contract with Iran. But the new Iranian leadership refused to honor the letter of credit issued by the central bank under the old regime. Gifted, Inc. and Lischem filed a claim at the International Court of Justice in The Hague. The sides attempted to reach a financial settlement out of court; there was a meeting in London between Gifted, Inc. representatives, the company's lawyers and Eerkens on the one side, and the AEOI on the other. The Iranians offered to pay 10 percent of the contractual price of the equipment supplied by Gifted. The company rejected the offer.[100] The Iranians then said they were willing to ship the equipment back to the United States; the company rejected that, too.[101] The case was then brought before the Iran–United States Claims Tribunal, which was set up in 1981 in accordance with the Algiers Accords to settle claims involving the two countries, their citizens, companies, and organizations.[102]

A hearing was conducted on April 13, 1984, in The Hague by three judges representing Iran, the Netherlands, and the United States. The Tribunal upheld the US plaintiff's claim and ordered the AEOI to pay Lischem the full sum agreed under the contract, $630,000, plus a late payment surcharge at 12 percent interest calculated starting from the date of expiry of the letter of credit. The court refused to consider Gifted, Inc. as a plaintiff because more than 50 percent of its shares were held by non-US citizens, meaning that its claims fell outside the Tribunal's remit. The Tribunal concluded that Lischem had discharged its contractual obligations and announced its ruling in favor of the company on June 22, 1984, more than five and a half years after the equipment was shipped to Iran. The money was paid from a special Security Account set up by Iran and the United States at the Dutch Central Bank when the Tribunal was created. Of the Iranians who negotiated the deal with Eerkens in 1976–78, only the head of the TNRC Laser Technology Division, Ehsanollah Ziai, and a senior expert of the Division, Reza Khonsari Mosavi, were involved in the Tribunal proceedings.[103]

In a written statement by the Tribunal, one of the three presiding judges noted that there were serious signs of fraud and bribery in the agreement reached between Gifted, Inc. and the AEOI. But the two other judges did not support the proposal to hold a special inquiry into these claims. A DOE representative who reviewed the Gifted, Inc. export license application in 1978 also noted that the price of the contract between the company and Iran was suspiciously high.[104] Two former Lischem engineers also testified that the agreement reached between Gifted, Inc. and AEOI included cash payments to Iranian representatives in return for facilitating the transfer of funds into the company's accounts.[105] But these allegations did not become the subject of any official investigation, and Naim Perry, the founder of Gifted, Inc., flatly rejected them.

In view of the ruling of the Tribunal, some of the wording used in International Atomic Energy Agency (IAEA) Director General Mohamed ElBaradei's November 2003 report entitled "Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran," concerning Iran's compliance with its nonproliferation commitments, appears imprecise. The report says, in particular, that the execution of the contract was "ultimately terminated."[106] In fact, cooperation between the AEOI and the Gifted-Lischem tandem did not continue (as was previously planned) after the equipment was delivered, but the US suppliers had fulfilled their side of the contract; the verdict of the International Court is unambiguous about that.

Laser Enrichment In Iran After The Islamic Revolution

The equipment supplied to Iran is believed to have spent more than six months (at least until the summer of 1979) at the customs transit warehouse at Tehran airport because the new leadership showed no interest in pursuing a nuclear program. Later on, the lasers and the ancillary equipment were brought to their intended destination, the Tehran Nuclear Research Center, where they sat in their shipping crates until late 1983.[107] Iranian specialists finally made an attempt to install the hardware in the mid-1980s, more than five years after the cargo was delivered, when the Iranian government decided to resume its nuclear programs and uranium enrichment research. Iran attempted to manufacture the missing parts of the enrichment unit, which were never supplied by Gifted, but, according to one expert, was unsuccessful.[108]

Following the outbreak of mass protests in Iran in early 1978—and especially after the Shah's departure from the country in early 1979—several states that were cooperating with the Shah's regime in the area of military and dual-use technologies began to evacuate their equipment, documents, advisors, and specialists. Some of the first to leave in June 1978 were the Israeli engineers working on the Flower project, a joint Iranian-Israeli effort to develop a surface-to-surface missile.[109] According to Israeli experts, all the project documents were also removed from Iran.[110] In October 1979, the US government managed to secure the consent of the transitional Iranian government for the removal of sensitive electronic equipment from advanced fourth-generation F-14 fighters previously supplied by the United States. In return, Washington agreed to resume the supply of aircraft spare parts.[111] US officials were also looking into the possibility of removing HEU fuel of US origin from the TNRC.

It appears, however, that the US government made no effort to remove from Iran the laser enrichment equipment supplied by Gifted, Inc., even though some experts at the Arms Control and Disarmament Agency and at the national nuclear laboratories had criticized the original plan to export it.[112]

After Iran resumed research into laser separation of uranium isotopes, it focused on AVLIS technology using equipment supplied by Germany and China.[113] According to a former IAEA official, significant resources were invested in that technology.[114] In the late 1990s, Iran approached Russian research institutes that make laser equipment with offers of cooperation.[115] It also had contacts with French and South African organizations, and bought from Australia mass spectrometers which were later used to provide analytical services (isotope enrichment measurements).[116] Eerkens says he has never been approached by the new leadership of the Iranian nuclear industry with any offers to resume cooperation on the molecular method of laser enrichment.[117]

In the early 1990s, the TNRC Laser Research Center (apparently created from the old Laser Technology Division), with Chinese assistance, set up a Laser Spectroscopy Laboratory and a Comprehensive Separation Laboratory to conduct research into AVLIS as a method of uranium enrichment.[118] The building where the two labs were located also housed the equipment designed by Eerkens. After making contact with his Iranian counterparts, the Russian nuclear energy minister, Victor Mikhailov, noted that the AEOI regarded laser technologies as an important priority for nuclear industry development, and that the research undertaken by the Iranians in the field was on a large scale.[119] It was later reported by the IAEA that the AVLIS technology had enabled Iran to enrich uranium to a maximum level of 13 percent.[120] These activities were not properly declared to the agency.

In May 2004, after the IAEA began investigating Iran's undeclared nuclear activities, Tehran announced that it had discontinued the laser enrichment program. It informed the IAEA that the equipment was dismantled in May 2003 and moved to a warehouse at the Karaj Agriculture and Medical Centre.[121] That claim was later verified during a visit to the site by IAEA inspectors. Then, on February 7, 2010, Iranian President Mahmoud Ahmadinejad announced that Iran possessed laser enrichment technology. As of January 2013, Iran has not provided any official explanations for that statement.[122] It confirmed, however, that it continued to pursue laser research.[123]

As for the equipment supplied by Gifted, Iran said that because some of the components were missing, the laboratory was never fully operational.[124] In October 2003, IAEA specialists inspected the presumed premises where the equipment for MLIS technology research was located. According to one of the agency's specialists, the irradiation chambers he was shown really did look as though they had never been used. According to the same source, environmental sampling also failed to detect anything suspicious.[125] But because neither the United States nor Iran had supplied any comprehensive information about the equipment delivered in 1978, the inspectors had no way of knowing whether the irradiation chambers they saw were the same ones supplied by Gifted.[126]

During their investigation of Iran's undeclared nuclear activities, IAEA inspectors did not have an opportunity to interview Eerkens officially (although they did speak to him in a private capacity at various science conferences).[127] The US government supplied the missing details in the mid-2000s by giving the IAEA information about Eerkens's cooperation with the AEOI.[128] The FBI and the US customs service had already investigated Eerkens, Lischem, and Gifted, Inc. for possible violations of US laws back in the early 1980s.[129] But the findings of those investigations were never publicly released. Information about the equipment for a laser enrichment laboratory supplied by Gifted, Inc. to Iran was provided to the IAEA more than twenty years after the investigation.

In parallel with AVLIS research, in the mid-1980s, the new Iranian government decided to prioritize the development of the gas centrifuge enrichment technology, which had already reached a degree of maturity in some other countries, and for which Iran could find assistance abroad (namely, in Pakistan). All the low-enrichment uranium that Iran has produced in substantial quantities, and which has now been placed under IAEA safeguards, was enriched using the gas centrifuge technology. Centrifuges were also used to produce the uranium enriched to 20 percent, which is the highest level of enrichment Iran has achieved so far.[130]

The Eerkens Technology: Afterword

In 1984, immediately following the conclusion of litigation with the AEOI and payment of the compensation awarded by the Tribunal, Naim Perry ended his cooperation with Lischem. Eerkens, meanwhile, continued to research the laser method of heavy isotopes separation using private financing. At a laser technology exhibition, he met Dick Griot, owner of Melles-Griot, a large maker of optical and laser equipment headquartered in Albuquerque, New Mexico. In 1980, the company signed a strategic partnership agreement with Lischem and undertook to finance Eerkens's research.

In 1985, Griot bought Lischem and the rights to the patents held by Eerkens. Griot then founded a new company, Isotope Technologies, Inc. (ITI). Eerkens became the owner of a 30 percent stake in ITI. The main objective of the company was to develop a commercially competitive technology for laser enrichment of uranium. The LISOSEP technology was renamed Chemical Reaction by Isotope Selective Laser Activation (CRISLA).[131] ITI began to look for a large strategic investor.

Australia was one of Melles-Griot's strategic markets. That is where Dick Griot met Michael Goldsworthy, founder and president of Silex, which was also developing a laser technology of uranium enrichment. Goldsworthy visited Los Angeles and the ITI laboratory; in 1988–90, the two companies began to exchange scientific data.[132] They negotiated a merger and were on the verge of setting up a joint venture in California. Silex and ITI lawyers had even prepared all the necessary documents, but two days before they were due to be signed, Dick Griot called the deal off after receiving information from an agent in Sydney that Silex was unable to invest sufficient resources of its own into joint projects.[133] Silex and Jeff Eerkens parted company. Almost twenty years later, in 2007, Silex made headlines after signing an exclusive deal with General Electric to commercialize its laser enrichment technology.

ITI, meanwhile, found a large investor in 1990. A joint venture was set up with Canada's Cameco, the world's largest producer of uranium at the time. ITI equipment was relocated from Los Angeles to Saskatoon, Saskatchewan, where the Canadian corporation kept its headquarters. Cooperation with Cameco ended three years later, in 1993, when significant quantities of Russian low-enriched uranium became available on the commercial market after fall of the Iron Curtain.[134] Cameco decided that it made better commercial sense to become a reseller of Russian uranium rather than continue investing in its own enrichment technology (an arrangement that ultimately did not pan out).[135] In 1993, the Cameco Board of Directors voted down, by four votes to three, a three-year, $50 million program for developing the CRISLA technology.[136]

All the equipment that had already been installed at Cameco was returned to ITI. Dick Griot, who had retired by that time, decided to give the equipment to his alma mater, the University of Missouri. For the first time since he moved to the United States in 1950, Jeff Eerkens left California and relocated to Missouri. Ten years later, after completing his stint as an adjunct professor at the University of Missouri, he returned to California and brought his equipment with him.

Eerkens holds more than fifteen patents for inventions related to the laser technology of uranium isotope separation and for other innovations. These patents are valid for seventeen years each, so most of them have already expired.[137] In 1995, Eerkens published a 728-page book, *Selected Papers on Laser Isotope Separation—Science and Technology*, which WalMart sold for $95.40 a copy.[138] The book is now available from Amazon.com for $114.

The first batch of the experimental laser enrichment equipment made by Eerkens for AEOI is now at the Karaj Agriculture and Medical Centre in Iran. Eerkens keeps the second batch (the laser, the optical system, and two irradiation chambers) in a warehouse near San Francisco, California. Ironically, before being returned to California, the equipment was stored in open barns at the College of Agriculture, Food and Natural Resources (a division of the University of Missouri).

Eerkens now has a new company, Prodev Consultants, and continues to look for opportunities for further improvement of his CRISLA technology. He believes that it can successfully compete with the Silex laser enrichment technology, which is now being commercialized by two giants of the global nuclear industry, GE-Hitachi and Cameco. Eerkens is convinced that his "Plan B" CRISLA technology approach, whose proof-of-principle was experimentally demonstrated in his 1986 tests, can produce reactor-grade uranium (3–5 percent enrichment) in just two cycles, compared to the five to ten cycles required by the gas centrifuge technology. [139] He estimates the required initial investment at $2 million.[140]

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NOTES

1. The word "laser" has become so commonplace that few remember what it actually stands for: Light Amplification by Stimulated Emission of Radiation.
2. "Кикоинские чтения: о лазерном обогащении урана" [The Kikoin Readings: On laser enrichment of uranium]," AtomInfo.Ru, April 3, 2009, <www.atominfo.ru/news/air6210.htm>.
3. Steven Hargrove, "Laser Technology Follow in Lawrence's Footsteps," *Science & Technology Review,* May 2000, <www.llnl.gov/str/Hargrove.html>.
4. Former senior IAEA official, interview with author, Washington DC, July 10, 2012.
5. Siavosh Moshfegh Hamadani, Laser Technology Division, Nuclear Research Center, Atomic Energy Organization of Iran, "Development of Laser Devices of Interest for Nuclear Applications in Iran: A Case Study of Parallel Technology Transfer," Proceedings of the Conference on the Transfer of Nuclear Technology, Vol. 1, Persepolis/Shiraz, Iran, April 10–14, 1977, p. 316.
6. International Atomic Energy Agency, "Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions 1737 (2006) and 1747 (2007) in the Islamic Republic of Iran. Report by the Director General," GOV/2007/58, November 15, 2007, p. 2.
7. "Progress report," Atomic Energy Organization of Iran, October-December 1975. Quoted in Mark Gorwitz, "The Iranian Nuclear Program–Laser Isotope Separation Early History and Its Current Implications," December 15, 1995, p. 3, James Martin Center for Nonproliferation Studies, Washington office archives.
8. Laser enrichment specialist Jeff Eerkens says he put the question to Mojtaba Taherzadeh, Director of the Tehran Nuclear Research Center, who replied that the hexafluoride for the MLIS technology would be obtained through cooperation with South Africa, and that an agreement to that effect had already been reached. Jeff Eerkens, interview with author, Paris, France, June 5, 2012; telephone interview with author, July 10, 2012.
9. According to Andy Lloyd, Chief Development Officer for Uranium at Rio Tinto, which now owns Rossing, the Iranian Foreign Investment Company still holds a stake in the uranium mine on behalf of Iran, but as of 2011 Iran had never received any uranium from that mine. See Andy Lloyd, "*Rio Tinto* открыта к сотрудничеству с АРМЗ и будет рада возможности поработать вместе" [Rio Tinto Open to Cooperation with ARMZ and Will Be Happy To Work Together], *Yadernyy Klub (Nuclear Club)*, No. 2, 2011, p. 32.
10. "Progress report," Atomic Energy Organization of Iran, October-December 1975, p. 2.
11. Reza Khonsari Mosavi, Laser Technology Division, Nuclear Research Center, Atomic Energy Organization of Iran, Tehran, Iran, "Laser Technology Transfer," Proceedings of the Conference on the Transfer of Nuclear Technology, Persepolis/Shiraz, Iran, April 10–14, 1977, Vol. 1, p. 316.
12. Large-scale cooperation between the Massachusetts Institute of Technology and the leading technology universities of Iran began in 1974.
    Jeff Eerkens, telephone interview with author, July 10, 2012.
13. Mosavi, "Laser Technology Transfer," p. 320; Siavosh Moshfegh Hamadani, Laser Technology Division, Nuclear Research Center, Atomic Energy Organization of Iran, Tehran, Iran, "Development of Laser Devices of Interest for Nuclear Applications in Iran: A Case Study of Parallel Technology Transfer," Proceedings of the Conference on the Transfer of Nuclear Technology, Persepolis/Shiraz, Iran, April 10–14, 1977, Vol. 1, p. 316; "Progress report," Atomic Energy Organization of Iran, October-December 1975, p. 4.
14. Siavosh, "Development of Laser Devices of Interest for Nuclear Applications in Iran: A Case Study of Parallel Technology Transfer," p. 318.
15. Gorwitz, "The Iranian Nuclear Program—Laser Isotope Separation Early History and Its Current Implications," p. 8.
16. The first Iranian specialists also graduated from the University of California–Berkeley Nuclear Engineering Department Master's Program in 1960.
17. Jeff W. Eerkens, speaker biography, Workshop on Laser Enrichment of Uranium, Department of Nuclear Engineering, University of California, Berkeley, January 26, 2009, <www.nuc.berkeley.edu/Colloquiums/2009-1-26>; The question of whether the use of nuclear weapons against Japan was justified has been debated by historians, politicians, and nuclear physicists for many decades. See, for example, Roland Timerbaev, "Насколько оправданным было применение ядерного оружия против

Японии?'' [The Bombing of Hiroshima and Nagasaki: A Justified Decision?], *Yadernyy Klub (Nuclear Club),* No. 2, 2010, pp. 42–44.

18. Jeff W. Eerkens, *The Nuclear Imperative: A Critical Look at the Approaching Energy Crisis (More Physics for Presidents)*, 2nd ed., (Dordrecht, The Netherlands: Springer, 2010), p. 195.

19. Eerkens, *The Nuclear Imperative*, pp. 195–96.

20. The merger of the Northrop and Grumman corporations in 1994 formed Northrop Grumman, America's largest aerospace and defense industry corporation. It employs over 70,000 people and from 2009–11 its annual revenues have never fallen below $26 billion. See the corporation's 2011 Annual Report, <www.northropgrumman.com/pdf/2011_noc_ar.pdf>.

21. In 1968, Eerkens received a patent for a direct nuclear-pumped gas laser, powered by the TRIGA Mk F pulsed reactor. The project was commissioned by the US Department of Defense.

22. Jeff Eerkens, telephone interview with author, July 10, 2012.

23. Dean A. Waters, Chief Scientist and Technical Manager, USEC, Inc., ''The American Gas Centrifuge: Past, Present, and Future,'' A Paper Presented to the Separation Phenomena in Liquids and gases Workshop, October 13, 2003, p. 6, <www.osti.gov/energycitations/servlets/purl/912770-dBuasR/912770.PDF>.

24. During Eerkens's time at Garrett, the corporation's work focused on testing gas centrifuges developed by Garrett itself and by Union Carbide Corporation (UCC) for an industrial-scale uranium enrichment facility. It was expected that Garrett Corporation could become the supplier of technology and equipment for a new enrichment facility in Piketon, Ohio. The value of the potential contract was estimated at $1 billion, and the facility's annual output at 9 million separative work units. President Jimmy Carter authorized the construction of the facility in 1977, but UCC won the contract. The construction of the Piketon facility began in 1980, but the project was suspended indefinitely in June 1985 after some $3 billion had already been spent. See Ole Pedersen, ''Developments in the Uranium Enrichment Industry,'' *IAEA Bulletin* 19, p. 45; Waters, ''The American Gas Centrifuge: Past, Present, and Future,'' p. 6.

25. Jozef W. Eerkens, *Rocket Radiation Handbook, Volume 1: Rocket Radiation Phenomenology and Theory* (Los Angeles: AiResearch Manufacuturing Company, Garrett Corporation, June 1974); Jozef W. Eerkens, *Rocket Radiation Handbook*, Volume II: Model Equations for Photon Emission Rates and Absorption Cross-Sections (Los Angeles: AiResearch Manufacuturing Company, Garrett Corporation, December 1973). Volume three of the handbook is classified in its entirety and is not available to the general public.

26. The separation factor is one of the key characteristics of any uranium enrichment technology. More effective technologies have a separation factor exceeding one. A low separation factor can be compensated for by passing the material being enriched through several stages (cycles), which form an enrichment cascade. For example, gaseous diffusion enrichment plants contain thousands of enrichment stages and are housed in buildings several hundred meters long. See Anton Khlopkov, ed., *Ядерноенераспространение Краткая энциклопедия* [*Nuclear Nonproliferation Encyclopedia*], (Moscow: Russian Political Encyclopedia, ROSSPEN, 2009), pp. 213–14; J.W. Eerkens, ''Spectral Considerations in the Laser Isotope Separation of Uranium Hexafluoride,'' *Applied Physics B: Lasers and Optics* 10, May 1976, p. 15.

27. See Khlopkov, ed., *Ядерное нераспространение Краткая энциклопедия* [*Nuclear Nonproliferation Encyclopedia*], p. 15.

28. Robert Gillette, ''Iran's Deal with L.A. Firm Widens Nuclear Capability,'' *Los Angeles Times,* August 22, 1979, p. B1.

29. Michael Rubin, ed., ''Meeting the Challenge: U.S. Policy toward Iranian Nuclear Development,'' Bipartisan Policy Center, September 1, 2008, p. 4, <http://bipartisanpolicy.org/library/report/meeting-challenge-us-policy-toward-iranian-nuclear-development>.

30. Jeff Eerkens, interview with author, Paris, France, June 8, 2012.

31. Jeff Eerkens, interview with author, Paris, France, June 7, 2012.

32. Ibid.

33. Gillette, ''Iran's Deal with L.A. Firm Widens Nuclear Capability,'' p. B1.

34. ''High Mass Isotope Separation Process and Arrangement,'' United States Patent 4082633, Column 31, <www.freepatentsonline.com/4082633.html?highlight=eerken&stemming=on>.

35. Eerkens deduced in later years that most of the chemical harvesting techniques described in the patent were unachievable, and that only the suppression of dimer formation (his ''Plan B'') could lead to successful economic uranium enrichment. See Jeff W. Eerkens, Jaewoo Kim, ''Isotope Separation by Selective Laser-Assisted Repression of Condensation in Supersonic Free Jets,'' *AIChE Journal* 56 (September 2010), pp. 2,331–37.
36. Jeff Eerkens, telephone interview with author, July 10, 2012.
37. J.W. Eerkens, ''Spectral Considerations in the Laser Isotope Separation of Uranium Hexafluoride,'' pp. 15–31.
38. Gillette, ''Iran's Deal with L.A. Firm Widens Nuclear Capability,'' p. B1.
39. Royal Dutch Shell sold its stake in General Atomics in 1982.
40. Jeff Eerkens, telephone interview with author, July 10, 2012.
41. Roland Timerbaev, ''Тажура-2: история несостоявшегося проекта'' [Tajura-2: The Project That Did Not Happen], *Yadernyy Klub (Nuclear Club),* No. 1, 2009, p. 34.
42. Jeff Eerkens, interview with author, Paris, France, June 7, 2012.
43. Jeff Eerkens, telephone interview with author, July 10, 2012.
44. Jeff Eerkens, interview with author, Paris, France, June 7, 2012.
45. The author received a copy of the letter from Eerkens.
46. ''Personal Items,'' *RSIC Newsletter*, Radiation Shielding Information Center, Oak Ridge National Laboratory, April 1975, p. 3, <http://rsicc.ornl.gov/Newsletters/news.75/news75.april.pdf>.
47. The project was launched in 1955 and ended in 1973. Its goal was to develop a compact 500–100 kW power unit for space exploration. The only launch of the unit to the earth orbit was conducted from Vandenberg Air Force Base on April 3, 1965, using the Atlas-Agena rocket. The project cost $850 million. For more details, see Susan S. Voss, ''SNAP Reactor Overview,'' Final Report, AFWL-TN-84–14 (Air Force Weapons Laboratory), August 1984, p. 1.
48. General Accounting Office, ''Circumstances Surrounding the Government's Approval of Nuclear-Related Exports To Iran,'' GAO Report EMD-80–44, March 17, 1980, p. 7, <http://archive.gao.gov/f0202/111869.pdf>.
49. Jeff Eerkens, interview with author, Paris, France, June 8, 2012.
50. Gillette, ''Iran's Deal with L.A. Firm Widens Nuclear Capability,'' p. B1.
51. Jeff Eerkens, telephone interview, July 20, 2012.
52. Gillette, ''Iran's Deal with L.A. Firm Widens Nuclear Capability,'' p. B1; The figures appear overly optimistic by a large margin.
53. Jeff Eerkens, telephone interview with author, July 20, 2012.
54. Office of Technology Assessment, *Nuclear Proliferation and Safeguards,* Appendix, Volume II, Part I, OTA-BP-ENV-177, June, 1977, pp. IV–43, 46, <www.fas.org/ota/reports/7714.pdf>.
55. General Accounting Office, ''Circumstances Surrounding the Government's Approval of Nuclear-Related Exports To Iran,'' pp. 7–8.
56. Gillette, ''Iran's Deal with L.A. Firm Widens Nuclear Capability,'' p. B1.
57. Jeff Eerkens, telephone interview with author, July 10, 2012.
58. S.R. Pirrie and J.S. Arnold, eds., *Iran-U.S. Claims Tribunal Reports*, Vol. 7, 1984, (Cambridge: Cambridge University Press, 1994), p. 23.
59. Gillette, ''Iran's Deal with L.A. Firm Widens Nuclear Capability,'' p. B1.
60. Pirrie and Arnold, *Iran-U.S. Claims for Tribunal Reports*, p. 20.
61. Jeff Eerkens, telephone interview, July 10, 2012.
62. Pirrie and Arnold, *Iran-U.S. Claims for Tribunal Reports*, p. 19.
63. Ibid.
64. Gillette, ''Iran's Deal with L.A. Firm Widens Nuclear Capability,'' p. B1.
65. Pirrie and Arnold, *Iran-U.S. Claims for Tribunal Reports*, p. 22.
66. Jeff Eerkens, telephone interview with author, July 20, 2012.
67. Jeff Eerkens, Interview with author, Paris, France, June 5, 2012.
68. General Accounting Office, ''Circumstances Surrounding the Government's Approval of Nuclear-Related Exports To Iran,'' pp. 4, 8.
69. Ibid., p. 5.

70. The 1978 Nuclear Nonproliferation Act was passed by the House of Representatives on September 28,1977, approved by the Senate on February 7, 1978, and signed by President Carter on March 10, 1978.
71. General Acccounting Office, "Circumstances Surrounding the Government's Approval of Nuclear-Related Exports To Iran," pp. 3.
72. Ibid., p. 5.
73. Ibid., pp. 4–5.
74. Department of State Memorandum, "Talking Points, The U.S.-Iran Nuclear Energy Agreement," October 20, 1978, Digital National Security Archive, <http://nsarchive.chadwyck.com>.
75. The plan was that Iran and the private US consortium Uranium Enrichment Associates (UEA), Japan, and several other countries would become the co-owners of an enrichment plant in Dothan, Alabama, worth $3.5 billion.
76. General Accounting Office, "U.S. Nuclear Non-Proliferation Policy: Impact on Exports and Nuclear Industry Could Not Be Determined," GAO Report ID-80–42, September 23, 1980, p. 39.
77. William Branigin, "Iran Orders 4 Reactors from West German Firm," *Washington Post,* November 11, 1977; "French Sign Iran A-Deal, Assail U.S.," Reuters, October 7, 1976.
78. General Accounting Office, "Allocation of Uranium Enrichment Services to Fuel Foreign and Domestic Nuclear Reactors," GAO Report ID-75–45, March 4, 1975, pp. 13–14.
79. Leonard S. Spector, *Going Nuclear* (Cambridge, MA: Ballinger, 1987), p. 51.
80. In October 1978, President Carter announced that friendship and partnership with Iran was one of the pillars of American foreign policy. See Semyon Agayev, "Иран между прошлым и будущим. События. Люди. Идеи" [Iran Between the Past and the Future: Events, People, Ideas], (Moscow: Politizdat, 1987), p. 21.
81. Spector, *Going Nuclear*, p. 55.
82. Ian Hoffman, "Iran Laser Program Shocks Experts," *Tri-Valley Herald,* November 12, 2003, <www.partnershipforglobalsecurity.org/PrinterFriendly.asp?Doc = 1113200320453PM.html#3G>.
83. Lischem advertisements carried by the leading specialist periodicals stated that the lasers made by the company were suitable for uranium enrichment.
84. General Accounting Office, "Circumstances Surrounding the Government's Approval of Nuclear-Related Exports To Iran," pp. 2, 4, 5.
85. Vladimir Fenopetov, "Почему Иран не смог совершить прыжок из Средневековья в ядерный век с шахом Пехлеви?" [Why Did Iran Fail to Make a Leap from the Dark Ages to the Nuclear Age under Shah Pahlavi?], *Yadernyy Klub (Nuclear Club)*. No. 2, 2011, pp. 54–55.
86. Ibid.
87. Anthony Parsons, *The Pride & the Fall: Iran 1974–1979* (London: Jonathan Cape, 1984), pp. 70, 137.
88. Agayev, "Иран между прошлым и будущим. События. Люди. Идеи" [Iran Between the Past and the Future: Events, People, Ideas], p. 19.
89. US Department of State, "U.S.-Iran Peaceful Nuclear Cooperation Agreement," Telegram, October 1, 1978, Digital National Security Archive, <http://nsarchive.chadwyck.com>.
90. Ibid.
91. Mohammad Reza Pahlavi, *Answer to History*, (NY: Stein & Day Publishers, 1980), p. 185.
92. Former senior Department of State official (who was in charge of the Middle East region at the time of the events described in this article), interview with author, Valday, Nizhniy Novgorod Region, Russia, June 30, 2012.
93. Pirrie and Arnold, *Iran-U.S. Claims for Tribunal Reports*, p. 20.
94. Ibid., p. 19.
95. Ibid., p. 20.
96. Gillette, "Iran's Deal with L.A. Firm Widens Nuclear Capability," p. B1.
97. Jeff Eerkens, e-mail correspondence with author, July 30, 2012.
98. Jeff Eerkens, telephone interview with author, July 20, 2012.
99. Mojtaba Taherzadeh died in the United States in 1996 at the age of 65. Akbar Etemad currently lives in France.
100. Jeff Eerkens, interview with author, Paris, France, June 5, 2012.
101. Spector, *Going Nuclear*, p. 260, note 94.

102. Some 4,000 disputes between private entities and seventy disputes between the Iranian and US governments were submitted to the Tribunal.

103. Adlam and Pirrie, *Iran-U.S. Claims for Tribunal Reports*, Vol. 7, 1984 – III, p.18.

104. General Accounting Office, "Circumstances Surrounding the Government's Approval of Nuclear-Related Exports To Iran," p. 3.

105. Gillette, "Iran's Deal with L.A. Firm Widens Nuclear Capability," p. B1.

106. International Atomic Energy Agency, "Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran. Report by the Director General," GOV/2003/75, November 10, 2003, Annex 1, p. 10.

107. Spector, *Going Nuclear*, p. 53.

108. Former senior IAEA official, interview with author, Washington DC, July 10, 2012.

109. For more details about the Flower project, see "Minutes from Meeting Held in Tel Aviv between H.E. General M. Dayan, Foreign Minister of Israel," and H.E. General H. Toufanian, Vice Minister of War, Imperial Government of Iran, "Top Secret Minutes from Israel's Ministry of Foreign Affairs," July 18, 1977, Digital National Security Archive, <http://nsarchive.chadwyck.com>.

110. Ephraim Kam, Deputy Director, Institute for National Security Studies (INSS), interview with author, Barcelona, Spain, January 25, 2012.

111. Spector, *Going Nuclear*, p. 260, note 97.

112. Gillette, "Iran's Deal with L.A. Firm Widens Nuclear Capability," p. B1.

113. A contract with China for laser equipment was signed by the AEOI in 1991. In 1985, the United States also designated AVLIS as a promising future technology of uranium enrichment, with the expectation that AVLIS would replace gaseous diffusion technology, which the United States relied on at the time. See Hargrove, "Laser Technology Follow in Lawrence's Footsteps," <www.llnl.gov/str/Hargrove.html>.

114. Former senior IAEA official, interview, with author, Washington DC, United States, June 27, 2012.

115. International Atomic Energy Agency, "Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions 1737 (2006) and 1747 (2007) in the Islamic Republic of Iran," GOV/2007/58, November 15, 2007, p. 2.

116. Ruben M. Serrato, "Laser Isotope Separation and the Future of Nuclear Proliferation," Dissertation. Com, October 2010, p. 52; Mark Hibbs, "Australia Tightened Oversight after Iran's Use of Spectrometer," *Nucleonics Week*, November 22, 2007, p. 5. Previously, Iran also bought mass spectrometers from several other countries, including Germany and France. According to IAEA specialists, these spectrometers are more suitable for analyzing uranium samples than the ones bought from Australia. Former senior IAEA official, e-mail correspondence with author, August 25, 2012.

117. Jeff Eerkens, interview with author, Paris, France, June 8, 2012.

118. International Atomic Energy Agency, "Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran. Report by the Director General," Annex 1, p. 10.

119. Former Russian official, interview with the author, Moscow, 2011.

120. International Atomic Energy Agency, "Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran. Report by the Director General," GOV/2004/83, November 15, 2004, p. 13.

121. Ibid.

122. International Atomic Energy Agency, "Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions in the Islamic Republic of Iran. Report by the Director General," GOV/2011/65, November 8, 2011, p. 5.

123. In order to be in compliance with Iran's safeguards, research should not include actual use of uranium. Otherwise, these activities must be properly declared to the IAEA. Former senior IAEA official, e-mail correspondence with author, August 25, 2012.

124. International Atomic Energy Agency, "Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran. Report by the Director General," GOV/2004/60, September 1, 2004, Annex, p. 7.

125. Former senior IAEA official, e-mail correspondence with author, August 25, 2012.

126. Former senior IAEA official, interview with author, Washington DC, July 10, 2012.

127. Jeff Eerkens, telephone interview with author, July 20, 2012.

128. Former senior IAEA official, interview with author, Washington DC, July 10, 2012.

129. General Accounting Office, ''Circumstances Surrounding the Government's Approval of Nuclear-Related Exports To Iran,'' p. 7.

130. According to the IAEA, as of May 2012, Iran has accumulated 232.8 kg of uranium enriched to 20 percent. See ''Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions in the Islamic Republic of Iran. Report by the Director General,'' IAEA, GOV/2012/55, November 16, 2012, p. 4.

131. This was originally known as Condensation Repression by Isotope Selective Laser Activation.

132. Silex was previously known as Australian Nuclear Enterprises.

133. Jeff Eerkens, telephone interview with author, July 20, 2012.

134. Jeff W. Eerkens, speaker biography, January 26, 2009.

135. Cameco also showed interest in building a uranium enrichment plant in Canada using Russian gas centrifuge technology, but the proposal was never implemented.

136. Jeff Eerkens, telephone interview with author, July 20, 2012.

137. See Free Patents Online, <www.freepatentsonline.com/result.html?p=1&query_txt=eerkens>.

138. Jeff W. Eerkens, *Selected Papers on Laser Isotope Separation—Science and Technology* (Bellingham, WA: SPIE Press, 1995).

139. Eerkens and Kim, ''Isotope Separation by Selective Laser-Assisted Repression of Condensation in Supersonic Free Jets,'' pp. 2, 331–37.

140. Jeff Eerkens, telephone interview with author, July 20, 2012.