



The centrifuge connection

After Iran's first story of how it acquired uranium enrichment technology was rejected, evidence of a more complex procurement network began to emerge.

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Iran has admitted to the International Atomic Energy Agency (IAEA) that it made secret efforts to procure the wherewithal to make sophisticated gas centrifuges to enrich uranium. But few believe that Iran has told the whole story of its extensive foreign procurements.

As of mid-January 2004, Iranian officials continued to insist that they obtained sensitive centrifuge drawings and components through "intermediaries," and that they did not know the original source of the items.

Recent Pakistani government investigations are undercutting that assertion and magnifying concerns that Iran has made only a partial declaration to the IAEA. Senior Pakistani gas centrifuge experts and officials have admitted to Pakistani government investigators that they provided centrifuge assistance to Iran, Libya, and North Korea. Details are sketchy at press time about who exactly was involved in these transfers, when they occurred, and how they were arranged. Although the Pakistani government has denied authorizing any of the transfers, characterizing them as the work of rogue scientists, evidence points to at least Pakistani government knowledge.

Iran had many other important suppliers. Individuals and companies in Europe and the Middle East also played a key role in supplying Iran's centrifuge program. China was the most important supplier to Iran's program to produce uranium compounds, including uranium hexafluoride, the highly corrosive gas used in centrifuges.

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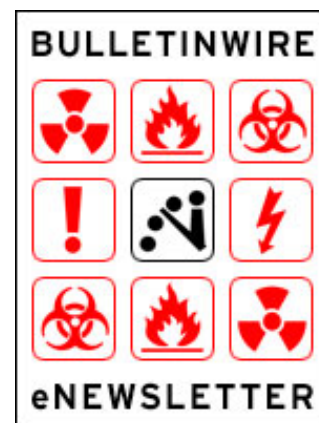
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Although Iran encountered many difficulties in making and operating centrifuges, postponing by many years the construction of a pilot centrifuge plant, it appears to have secretly achieved self-sufficiency in centrifuge manufacturing by the mid-to late 1990s.

Although Western intelligence agencies detected many of Iran's sensitive procurements, they missed some key ones. Because it had only incomplete information, the United States had trouble convincing its allies until 2002 or 2003 that Iran's effort to build secret gas centrifuge facilities had reached an advanced state (see "What the United States Knew," p. 63). Lacking actionable information or intrusive inspections, the International Atomic Energy Agency (IAEA) was unable to determine until recently that Iran had significantly violated its obligations under the Nuclear Non-Proliferation Treaty (NPT).



The program begins

Iran stated in its 2003 declarations to the IAEA that it began its gas centrifuge program in 1985 during its bloody war with Iraq. This decision is widely perceived as having been part of an effort to make highly enriched uranium for nuclear weapons.

Iran claimed that the only purpose of its centrifuge program was to make fuel for the German-supplied Bushehr power reactor--a claim that is highly dubious, given the reality that in 1985 Germany had suspended all work at the reactor, at least until the war ended. After the war, Germany never resumed construction. In early 1995, Russia signed a contract to finish the reactor. Yet throughout the decade, when the fate of the reactor at Bushehr was uncertain, Iran accelerated its gas centrifuge program.

Little information is available about Iran's initial efforts in 1985. What information did it already have about centrifuges, since modern designs are all classified? What design did the program first study? What were its initial plans? Had there been offers of assistance from Pakistanis or other individuals that encouraged the Iranians to start the program?

Iran quickly began procuring items. For example, in 1985 it acquired key "flow-forming" equipment, useful in forming steel and aluminum centrifuge tubes, from the German firm Leifeld. At least one Leifeld flow-forming machine is currently used in Iran's gas-centrifuge manufacturing complex. Leifeld personnel could have been knowledgeable about centrifuges when they sold the items to Iran. (It is known that around 1987, Leifeld demonstrated its flow-forming equipment in Iraq, showing a video containing sensitive information about producing maraging steel rotors for a Urenco-type gas centrifuge.)

In 1987, Iran made a significant breakthrough, obtaining a complete set of centrifuge drawings and some centrifuge components. This specific procurement may have been part of a much larger package that helped Iran understand and build centrifuges.

Acquiring the drawings and a few components was tremendously helpful. With detailed designs in hand, Iran could skip many difficult research steps. It was unlikely to have had the technical experience to discover the intricacies of a modern centrifuge or master the difficult manufacturing of centrifuge components on its own--Pakistan and Iraq also needed to obtain

detailed centrifuge designs and assistance for their centrifuge programs to advance beyond a rudimentary level.

Armed with component specifications and drawings, Iran would be able to design and implement a strategy to develop a reliable centrifuge and create a manufacturing infrastructure to make thousands of centrifuges. It would be able to find foreign companies to make specific components, often unwittingly. In parallel, it could locate companies that would sell the equipment Iran needed to make the components itself.

Iran acquired drawings of a modified variant of an early-generation Urenco centrifuge built by the Netherlands. Some experts familiar with these drawings have assessed that, based on the design's materials, dimensions, and tolerances, it is a modified precursor to the Dutch M4 centrifuge. This design has four aluminum rotor tubes connected by three maraging steel bellows. The rotor has a diameter of 100 millimeters and the entire machine is about 2 meters tall.

However, inspectors noticed that someone modified the design in distinctive ways. In addition, the original drawings were shown to inspectors, and their labels are in English, not Dutch or German. According to intelligence information, the design resembles one built by Pakistan in the 1980s and early 1990s that is sometimes called the P1. In addition, the centrifuge components Iran bought match those bought by Pakistan.

There was other evidence that pointed to Pakistan as the source of the drawings and of at least some of the components. Much of the highly enriched uranium that the IAEA found in Iran by taking environmental samples may be consistent with material produced in Pakistan.

Who provided these drawings?

The media have reported that senior Pakistani gas centrifuge officials, including Abdul Qadeer Khan, the father of Pakistan's centrifuge program, provided multiple centrifuge designs to Iran and other countries. As of late January, however, no charges had been filed against any of the officials.

Last fall, Iran provided the IAEA with a list of five middlemen and company officials who, it said, provided the drawings and other key items. Iran characterized these middlemen, who are European and Middle Eastern, as putting together orders--buying items from various companies and delivering them to Iran.

The exact role of some of these individuals is murky. Did they act as agents of their respective companies, or were they acting alone as consultants? They are also believed to have supplied or arranged shipments of items to Pakistan.

Of those named, three are Germans who were involved in selling a range of dual-use and other civilian and military items to Pakistan, many countries in the Middle East, and elsewhere.

Iran's statement to the IAEA implied that one or more of the three Germans obtained a classified centrifuge design from Pakistan and sold it to Iran.

It is more likely that a Pakistani or group of Pakistanis provided the drawings to Iran along with the names of those Iran could approach for help in acquiring components and essential items. Any Pakistanis involved in this scheme would likely have been from the Khan Research Laboratories, where the Pakistani centrifuge program is based.

The Pakistanis' main motivation would probably have been financial. In the mid-1980s, connections between Iran and Pakistan were growing in many areas. In addition, the Pakistani gas centrifuge program or its members may have needed money.

In any case, the drawings are unlikely to have been provided by themselves. Based on proven and alleged cases involving Iraqi and Pakistani centrifuge experts, the sale of centrifuge drawings is often a "sweetener" or accompanied by offers for the sale of other, more profitable items, such as materials, components, or machine tools to make components. Thus, Iran's statement about its procurements of drawings and some components in 1987 and the naming of a handful of individuals is consistent with the start of significant assistance from knowledgeable Europeans, Middle Easterners, and Pakistanis.

Iran's procurements

In the 1980s, Iran created an extensive procurement system to acquire necessary items for its centrifuge program from around the world. It used front companies to order the equipment and falsely declare non-nuclear uses, and it established secret transportation routes.

These efforts were not always successful. Alert government or company officials stopped many orders. Some of Iran's purchases involved defective centrifuge components. Nonetheless, over many years, Iran succeeded in acquiring thousands of sensitive centrifuge components and all the equipment it needed to be self-sufficient in the manufacture of centrifuges. In its quest, foreigners played key roles in organizing the purchase and shipment of items.

In late 2003 Iran provided the IAEA with a long list of equipment suppliers, including when the equipment was purchased. Iran has also not removed or otherwise hidden nameplates that contain company names and serial numbers.

In the late 1980s and early 1990s, many of the items Iran wanted were loosely controlled by national or international export controls. Many were acquired legally, at least in the sense that suppliers did not knowingly break the then-lax export control laws and government bureaucracies did not scrutinize the exports for their actual purpose.

Iran acquired a long list of items, including high-strength aluminum, maraging steel, electron beam welders, balancing machines, vacuum pumps, computer-numerically controlled machine tools, and flow-forming machines for both aluminum and maraging steel. Many of these items were obtained in Europe, especially from Germany and Switzerland. Suppliers trained Iranians in the use of critical equipment and taught them associated technologies needed in a centrifuge program.

The assistance of at least some of the named middlemen would have been important. They would have known which companies could provide desired items and which would be willing to do business with Iran. If any of these individuals had extensive knowledge about centrifuges and their manufacture, their help could have been invaluable in identifying the right suppliers of equipment, materials, and the necessary know-how.

Components

During its initial procurement effort in the late 1980s and early 1990s, Iran acquired only a limited number of centrifuge components. The number was consistent with a program that was then focusing on trying to build and operate single centrifuges for testing.

But then, as Iran has said, between 1993 and 1995, it received through middlemen enough components to build 500 centrifuges. It is from centrifuges made from these imported components that traces of highly enriched uranium have been found by the IAEA, at both the site at Natanz and at Kalaye Electric in Tehran.

As of late January 2004, the manufacturer of these components has not been publicly identified, and Iran has yet to provide any documentation about this purchase. On the surface, Iran appears so far to be protecting the actual supplier of these components.

Putting in such a large order would imply, however, that Iran had now decided on a particular centrifuge design. It also indicates that by the mid-1990s Iran was ready to build a major cascade or pilot plant.

This order included large numbers of the most sensitive centrifuge components, including bellows, which raises troubling questions about the effectiveness of export controls at a time when they were being tightened throughout Europe--and after Pakistan had given the United States assurances it would not engage in such assistance.

There are several theories about the origin of these components, including:

European, Pakistani, or other companies made the components to specifications provided by middlemen, Iranian agents, or Iranians in the centrifuge program themselves; or

Pakistan sold off surplus components that it made itself or purchased in Europe or in developing countries. Pakistan is known to have replaced its P1 centrifuge with a more advanced P2, or all-maraging steel rotor machine, starting in the mid-1980s. By about 1995, Pakistan had probably phased out most of its P1 machines and had extra, unused components left over.

Questions of timing

Despite importing all these components, Iran said in its statements to the IAEA in 2003 that it had trouble getting the centrifuges to work. It has declared that it did not enrich any uranium until 1999, and then produced

uranium enriched to no more than 1.2 percent uranium 235. This statement, however, is very much at odds with the process of settling on a design. Typically, before building a large number of centrifuges, program leaders want to test the design with uranium hexafluoride.

Iran told the IAEA that in addition to problems with the quality of the imported components and the difficulty it encountered making components of sufficient quality for high-speed centrifuges, it also had problems assembling and running centrifuges. These factors led to delays. In addition, the need for increased secrecy and security led to a decision in 1995 to move out of the existing facility in Tehran, causing further delays.

Shutting down the sophisticated operations in Tehran may have also been motivated by increased international scrutiny, particularly in 1995. In any case, before the IAEA accepts Iran's declaration, the timing of the program needs to be better understood.

Declared facilities and activities

According to Iranian declarations in October and November 2003, until 1997 the centrifuge program was centered at Iran's Atomic Energy Organization facilities in Tehran, with laboratory work conducted at the Plasma Physics Laboratory of the Tehran Nuclear Research Center. The first head of the gas centrifuge program was a former head of Iran's plasma physics program.

Iran told the IAEA that in 1997 the majority of the program was relocated to Kalaye Electric in Tehran. This move, which was motivated partly by the need for additional security, was difficult and caused further delays in the program. Nonetheless, from 1997 to 2002, Iran operated single machines and small cascades of 10-20 machines, achieved the ability to make all the components itself, and gained some success in testing centrifuges both with and without uranium hexafluoride. It also decided to construct enrichment facilities at Natanz.

In 2002, research, development, and assembly operations were moved to Natanz. This facility is now the primary site of the Iranian gas centrifuge program. It consists of centrifuge assembly areas and a pilot fuel-enrichment plant slated to hold 1,000 centrifuges. A production-scale fuel-enrichment plant is under construction at Natanz, and is scheduled to hold about 50,000 centrifuges. Before it voluntarily suspended activity in November 2003, Iran was operating both single machine tests and small cascades with uranium hexafluoride at the pilot plant.

Before the suspension, Iran was assembling four-rotor machines similar to the P1 design. Each has a separative capacity of roughly 3 separative work units (swu) per year. Earlier, based on information that the capacity was about 2 swu per year, we had speculated that Iran had a centrifuge with two aluminum rotor tubes connected by a bellows, and the machine was properly optimized to produce enriched uranium. Based on more recent information, our current understanding is that the Iranian machine is as described above and that it is not optimized.

Although the pilot plant is relatively small, if finished, it could produce about 10 kilograms of weapon-grade uranium a year, depending on the "tails assay" (the fraction of uranium 235 lost to waste) and the manner in

which the centrifuges are organized into cascades. Because centrifuges are flexible, even if the cascades are arranged to produce only low-enriched uranium, weapon-grade uranium can be produced by "batch recycling"-- sending the end product back into the feed point of the cascade over again until the desired level of enrichment is reached.

We project that the production plant could eventually have a capacity of at least 150,000 swu per year--enough capacity to provide annual reloads of the nearly completed power reactor at Bushehr, but far short of the enriched uranium it would need to provide fuel for all the civilian power plants Iran plans to build over the next 20 years.

Alternatively, the same capacity could be used to produce roughly 500 kilograms of weapon-grade uranium annually. At 15-20 kilograms per weapon, that would be enough for 25-30 nuclear weapons per year.

Natanz could be operated to make low-enriched uranium fuel until Iran decided it wanted to make weapon-grade material. It wouldn't take long to enrich the low-enriched material to weapon grade. For example, if Natanz was operating at full capacity and recycled the end product--low-enriched uranium (5 percent uranium 235)--back into the feed point, the facility could produce enough weapon-grade uranium for a single weapon within days.

Planning for the future

Iran's centrifuge procurement effort involved extensive secret procurement networks, both before and after the 1991 Persian Gulf War, when nations were tightening their export controls on sensitive items. Understanding just what Iran did, how it got help, and who helped, are critical in verifying Iran's declarations to the IAEA, and in identifying and fixing weaknesses in existing national and international export controls.

There is as yet only a sketchy answer to the question of who, exactly, provided sensitive centrifuge drawings and components to Iran. The footprints are being traced, however. Complete declarations from Iran and honest investigations by Pakistan of its past activities are needed to fill out the picture of Iran's extensive procurement activities for its centrifuge program and Pakistani scientists' assistance to Iran's and others' secret nuclear programs.

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Sidebar: What the United States knew

A critical period in Iran's centrifuge program was the early and mid-1990s, before it became largely self-sufficient in making centrifuges. During this period, Western intelligence agencies, particularly U.S. agencies, obtained some evidence that Iran was attempting to acquire centrifuge technology. However, neither Russia nor any European government was sufficiently convinced to take action to stop Iran's centrifuge effort.

Most U.S. actions focused on trying to convince Russia to stop cooperating with Iran's nuclear program. The United States failed to get Russia to agree not to complete the power plant at Bushehr, but it did convince Russia not to sell Iran a centrifuge plant or other sensitive nuclear facilities (see my article "An Iranian Bomb?" July/August 1995 *Bulletin*). At the same time, the U.S. government did not believe or act as if Pakistan was a critical supplier of centrifuge know-how to Iran.

By the early 1990s, Iran was known to have acquired or tried to acquire many items that were indicative of a centrifuge program. These known procurements led U.S. intelligence agencies to conclude that Iran had at a minimum gained access to a list of German companies, indicating that the Iranians knew what items they should procure.

Some procurements were for centrifuge components or their "preforms," which had dimensions identical to Urenco designs. Italian intelligence reported that Sharif University in Tehran placed an order in 1991 for centrifuge components with the Austrian firm Tribacher. This firm does not make centrifuge components per se, but it does make ring magnets to a customer's specifications and these magnets can be used in the upper bearing of a Urenco-type centrifuge. Tribacher also made ring magnets for Iraq's Urenco-based centrifuge program before the 1991 Persian Gulf War. These procurements implied that Iran had acquired at least some Urenco designs.

One recurring complaint of skeptical Europeans and IAEA officials was that the information supplied by intelligence agencies often did not include whether Iran had successfully obtained a mentioned item, and foreign intelligence agencies were unable to verify that a transaction had occurred. Based on their interpretation of the evidence, several officials were willing to accept only that Iran was interested in centrifuges. They were unwilling to believe that Iran had a substantial secret program.

In early 1995, one senior U.S. intelligence official told me about some of the difficulties the United States faced in making its case about the existence of secret Iranian nuclear activities. The United States did not know where centrifuge activities were occurring in Iran. Instead, the United States had to base its case largely on the procurement activities it had detected. If someone doubted whether Iran had a significant secret nuclear program, he said, information of the type known to the United States was unlikely to sway skeptics to the U.S. position.

Interestingly, Pakistan was suspected as a source of the centrifuge designs by the early 1990s, although direct proof was lacking. One senior European with deep knowledge of European companies who secretly aided centrifuge programs, and who had also heard U.S. intelligence officials' briefings on Iranian procurement activities, told me in early 1995 that Pakistan might have sold Iran a drawing of a centrifuge assembly. He also said that U.S. intelligence believed that Iran acquired shipments of machine tools for its centrifuge program through Pakistan. Jim Hoagland of the *Washington Post* reported on May 17, 1995 that Iran was pursuing a nuclear weapon acquisition "blueprint" drawn up at least four years before with the aid of Pakistani officials.

U.S. intelligence was aware of Iran's management problems and weaknesses in its science and technology sectors, and had concluded that Iran would need many years to build a pilot enrichment plant. The senior U.S. intelligence official mentioned earlier also told me that Iran was having difficulties with its centrifuge program and would need as many as seven years to build a pilot plant to make highly enriched uranium.

Increased scrutiny, however, appears to have affected the program in 1995. Iran told the IAEA that it shut down its operations in Tehran at a modern, well-equipped site because of concerns about security. The new site at Kalaye Electric was much better hidden from prying eyes. Even its name was non-nuclear and unobtrusive. In English, Kalaye Electric means roughly "electrical goods." The senior intelligence official later told me that after a period of frequent discoveries of Iranian procurement efforts, the number of detections radically decreased. The resulting assessment was that Iran had probably gotten better at hiding procurements of critical items. Newer evidence suggests that Iran had obtained the bulk of the manufacturing equipment it needed by the mid-1990s.

In the mid-1990s, intelligence agencies appear to have missed much of Iran's success in acquiring a large number of centrifuge components and underestimated the progress of the program. However, U.S. intelligence estimates about the time Iran needed to build a pilot plant have turned out to be reasonably accurate. Overall, the intelligence agencies correctly identified that they were seeing only the tip of the iceberg of Iran's centrifuge program and procurement efforts. But the "tip" was not viewed in Europe or Russia as convincing evidence of a secret, advanced gas centrifuge program warranting a significant response. After the mid-1990s, according to former senior U.S. government officials, U.S. intelligence agencies learned little concrete about Iran's centrifuge progress.

As a result, there was little concerted action until 2002 to stop Iran's secret centrifuge program or demand far more intrusive IAEA inspections in Iran. From 1995 until 2002, Iran moved relatively freely and secretly toward building a domestic centrifuge industry that could enrich significant quantities of uranium.

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