As Crisis Brews, Iran Hits Bumps in Atomic Path

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When Iran defiantly cut the locks and seals on its nuclear enrichment plants in January and restarted its effort to manufacture atomic fuel, it forced the world to confront a momentous question: How long will it be before Tehran has the ability to produce a bomb that would alter the balance of power in the Middle East?

Iran's claims that it is racing forward with enrichment have created an air of crisis as the board of the International Atomic Energy Agency prepares to meet tomorrow in Vienna before the United Nations Security Council takes up the Iran file for possible penalties.

Yet behind the sense of immediate alarm lies a more complex picture of Iran's nuclear potential. Interviews with many of the world's leading nuclear analysts and a review of technical assessments show that Iran continues to wrestle with serious problems that have slowed its nuclear ambitions for more than two decades.

Obstacles, the experts say, remain at virtually every step on the atomic road. The most significant, they add, involve the two most technically challenging aspects of the process — converting uranium ore to a toxic gas and, especially, spinning that gas into enriched atomic fuel.

According to the analysts, the Iranians need to do repairs and build new machines at a prototype plant before they can begin enriching even modest quantities of uranium. And then, for a decade, they would have to mass produce 100 centrifuges a week to fill the cavernous industrial enrichment halls at Natanz. What is more, the gas meant to feed those machines is plagued by impurities.

The perception gap was underscored in February when Tehran issued a stark warning. By late this year, Iranian officials said, they would begin installing nearly 3,000 centrifuges at the giant Natanz plant, buried deep underground to withstand attack. That many centrifuges, international inspectors knew, could make fuel for up to 10 nuclear warheads every year.

In Washington and Europe, the announcement was dismissed as an empty boast. "Maybe they can move that fast," said a senior American official who tracks Iran's program but who declined to be named because it is an intelligence matter. "But they would need lots of help, luck and prayer."

Tehran maintains that it has every right to master the atomic basics in pursuit of a peaceful program of nuclear power. But more and more countries have come to view that as a cover story.

Estimates of just when Iran might acquire a nuclear weapon range from alarmist views of only a few months to roughly 15 years. American intelligence agencies say it will take 5 to 10 years for

Iran to manufacture the fuel for its first atomic bomb. Most forecasters acknowledge that secret Iranian advances or black market purchases could produce a technological surprise.

Conservative forecasts often take into account not only the technical difficulties but also a political judgment: that Tehran will run for the finish line — making its first bomb — only when it can rapidly produce a large arsenal.

A further uncertainty is defining the exact point at which Iran's nuclear program would become an unstoppable threat. While most analysts identify the greatest danger as when Iran can produce nuclear fuel — the hardest part of the bomb venture, far more difficult than designing a warhead — others, particularly the Israelis, say the tipping point may come earlier, when Tehran has accumulated a critical mass of atomic knowledge.

For all the bluster and anxiety of the moment, Iran's atomic history is a conundrum of delay: given its wealth of atomic scientists and oil revenues, why was Tehran unable to succeed years ago?

After all, it took only three years for the United States to build the world's first atom bomb. It took Pakistan and North Korea, poor by Western standards, roughly a decade to get enough material for their first nuclear devices. Iran, by most estimates, has been moving toward the same objective for at least two decades.

Some of Iran's nuclear troubles can be traced to wavering political commitment by mullahs more interested in creating a theocracy than unlocking the secrets of the atom. And many top scientists fled after the Islamic revolution of 1979.

But the United States created other obstacles. In the 1990's, it pressured Russia, China and other nations to end deals that would have given the Iranian program a jump-start. Some of those maneuvers were covert; some played out in the press.

"In retrospect, we impeded a lot more of their progress than we knew," said Robert J. Einhorn, a central player in nuclear diplomacy in the Clinton administration and the early days of the Bush administration.

In Washington and around the world, assessments of Iran's technological maturity have driven deliberations over what to do. American and Israeli planners have quietly debated the possibility and the risks of military strikes, including whether they would be more effective soon or only after Iran has built a much larger infrastructure.

At least publicly, though, the Bush administration has followed a different strategy than it did with Iraq. After the failure to discover weapons of mass destruction there, President Bush has never argued that Iran poses an imminent threat, and his aides have called for diplomacy.

"There are still certain techniques and pieces of know-how that we do not believe that they have," Sean McCormack, a State Department spokesman, said in February.

Most experts focus on uranium and ignore Iran's work on plutonium, another bomb fuel, judging it as even further from fruition. Still, nuclear analysts warn against complacency.

"They do have serious problems," said Mohammad Sahimi, a chemical engineer at the University of Southern California who left Iran in 1978. "But we've made mistakes in underestimating the strength of science in Iran and the ingenuity they show in working with whatever crude design they get their hands on."

Centrifuges and Uranium

By all accounts, the oldest and most daunting problem involves centrifuges — temperamental machines whose rotors can spin extraordinarily fast to enrich uranium. After two decades of effort, Iran seems barely out of the starting gate.

All uranium is not equal. One form, uranium 235, easily splits in two, or fissions, in bursts of atomic energy that power nuclear reactors and bombs. Its slightly heavier cousin, uranium 238, does not.

But since uranium 235 accounts for less than 1 percent of all uranium, engineers use centrifuges to separate the two and concentrate the rare form. Uranium enriched to about 4 percent uranium 235 can fuel most reactors; to 90 percent, atom bombs.

In 1987, the Iranians secretly began buying drawings and parts for centrifuges from Abdul Qadeer Khan, the Pakistani nuclear expert who operated the world's biggest nuclear black market. International inspectors say the deals eventually included parts for about 500 primitive used centrifuges.

Tehran, apparently unhappy with their quality, turned to Moscow. In early 1995, it made a secret deal to buy an entire plant of centrifuges — typically tens of thousands of the spinning machines linked together to slowly increase the level of enrichment.

But after the Clinton administration persuaded Moscow to back out, Iran accelerated its secret drive to copy Dr. Khan's centrifuges. It also started building the huge enrichment plant near Natanz, in central Iran. The pilot factory there was to house 1,000 centrifuges; the main plant would shelter 50,000 machines underground.

In August 2002, Iranian dissidents revealed the existence of the Natanz site, beginning the current confrontation with the West. The next year, Iran agreed to suspend work while negotiating with Europe over the program's fate.

But when operators shut down an experimental cascade of 164 centrifuges at Natanz, about 50 of them broke or crashed, according to a January report by David Albright and Corey Hinderstein of the Institute for Science and International Security, a private group in Washington.

Now, the report said, Iran must replace and repair the broken machines and prepare the cascade for operation. Then comes the really hard part: if all goes well, the Iranians must mass-produce thousands of centrifuges and learn to run them in concert, like a large orchestra.

Iran is also struggling to turn concentrated uranium ore, or yellowcake, into uranium hexafluoride, the toxic gas fed into the centrifuges for enrichment. Such conversion is done at a site on the outskirts of Isfahan.

Iran began the conversion effort in the early 1990's, asking China to help build the complex. But in 1997, the Clinton administration persuaded Beijing to stop the deal. The Iranians got blueprints but little else. So they started building on their own.

"From what I saw, everything looked like local manufacturing except for some gauges," said Gary S. Samore, who ran the National Security Council's nonproliferation office during the Clinton administration and who traveled to Isfahan in 2005.

Iran, which tried to hide most of its nuclear sites, voluntarily revealed Isfahan to international inspectors in 2000. But the plant encountered problems during its first runs in early 2004, its output laced with impurities, in particular molybdenum, a silvery element often found in uranium ore.

The contamination, experts say, can ruin delicate centrifuges, reducing their efficiency and cutting short their lifetimes.

The Iranians are working hard to solve the problem. Mark Hibbs of Nuclear Fuel, an industry publication, who broke the molybdenum story, said most experts believed that the Iranians would ultimately succeed. British intelligence, he said, put the time needed at a year and a half, Israeli analysts at two or three months.

Houston G. Wood III, a centrifuge expert at the University of Virginia, said the Iranians might simply learn to cope. "If you're smart enough," he said, "you could probably get by, maybe with decreased efficiency."

Western officials worry that the conversion has a secret side run by a military group seeking to integrate the nuclear program with the design of missiles that could deliver a weapon. In a Jan. 31 report, the I.A.E.A. revealed that it had documentary evidence of a shadowy operation, the Green Salt Project. Tehran dismissed the charge of a hidden military effort as baseless and later called the documents forgeries.

Estimating a Bomb's Birth

Atomic forecasts are driven largely by assessments of technological maturity, sometimes colored by judgments of the risks of guessing wrong.

That may explain the gulf between Israel's claim that the world has as little as six months before the "point of no return" and estimates that an Iranian warhead is many years away.

"We live within Iranian missile range," said a senior Israeli official who has worked on the country's estimates. "Our survival depends on understanding the worst-case scenario." Thus, in the Israeli view, it would be a huge mistake to let the Iranians figure out how to clean up and enrich their uranium.

Israel cites studies like one published in October by the Strategic Studies Institute of the Army War College, "Getting Ready for a Nuclear-Ready Iran." Its timeline is short, one to four years. Iran, it asserted, "lacks for nothing technologically or materially to produce it, and seems dead set on securing an option to do so."

Henry Sokolski, an editor of the report, said neither he nor anyone else could actually produce a truly accurate forecast. "A lot of people are fraudulent, making it sound like a science," he said. "It's not."

He nonetheless defended the report's estimate as reasonable, pointing to Iran's long nuclear history.

Analysts like Mr. Albright and Ms. Hinderstein of the Institute for Science and International Security put the earliest date Iran might produce a weapon at 2009.

To date, the most comprehensive public estimate is by the International Institute for Strategic Studies, an arms analysis group in London. "If Iran threw caution to the wind," John Chipman, the institute's director, said, it might be able to make fuel for a single nuclear weapon by 2010.

Dr. Samore, who edited that report and is now at the MacArthur Foundation, said the Iranians might see political advantage in a more deliberate approach, doing nothing provocative until after 2015 or even 2020.

In his view, he said, Iran would complete the main Natanz plant, installing 50,000 centrifuges and learning to operate them. If successful, it could then enrich uranium to the low levels needed for a nuclear reactor and so comply with the Nuclear Nonproliferation Treaty.

Then it could rush ahead and produce enough highly enriched fuel for a nuclear arsenal in weeks or months. At full tilt, the report concluded, Natanz could annually churn out material for up to 180 warheads.

Such a "breakout" chain of events worries experts because it leaves the world little or no time to react.

Seeking a Global Strategy

The Bush administration has concluded that even if Iran stops short of assembling a weapon, its ability to produce one on short order would change the politics of the Middle East. So it has been trying, with mixed success, to devise a broader atomic blockade that would turn the unilateral, often clandestine efforts of the past into a far more global effort involving not only Europe but India, China and Russia. In theory, the meeting this week in Vienna is a step in that direction.

But administration officials are also trying to make headway on their own. They have persuaded several of Iran's neighbors — they will not say which ones — to block Iranian cargo flights that appear headed toward North Korea or other potential nuclear suppliers. Last year, that strategy appeared to succeed in at least one case, when China intervened.

In a little-noted speech in February, Robert Joseph, an under secretary of state and one of the administration's leading hawks on Iran, described the tools of denial he was employing, from cracking down on Tehran's finances to depriving Iran of crucial technologies.

But administration officials readily acknowledge that it is next to impossible to build a leak-proof wall. In his speech, Mr. Joseph warned of the "wild card" that Iran could obtain nuclear fuel for a bomb from an outside supplier.

As much as anything, officials worry about the unknown. They note that the United States missed signs that a country was about to go nuclear with the Soviets in the 1940's, the Chinese in the 1960's, India in the 1970's and Pakistan in the 1990's.

"People always surprise us," said a senior nuclear intelligence official who was not authorized to speak publicly. "They're always a little more cunning and capable than we give them credit for."

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