FEATURES

UNSANCTIONED SCIENCE

PHOTO: BABAK TAFRESHI/THE WORLD AT NIGHT

Despite penury and isolation, Iran's scientists have pursued an ambitious agenda. If sanctions end, research will blossom

By **Richard Stone**, *in Tehran*

Not far from Qazvin, an ancient Persian capital known for fine calligraphy, a new monument to learning will soon be built. If all goes well, construction of Iran's first synchrotron, a source of brilliant x-ray light for studies of everything from biological molecules to advanced materials, will begin in 2018. The $300 million Iranian Light Source Facility (ILSF) is the country's biggest basic science project ever—and expectations are high inside and outside the Islamic republic. The synchrotron "will offer Iran the potential to do world-class science," says David Attwood, an applied physicist at the University of California, Berkeley, who visited the ILSF's office in Tehran last year.

The project is a testament to the country's determination to do science in spite of turmoil, political interference, and the viselike grip of economic sanctions imposed by the United States and its allies to block Iran's suspected effort to develop nuclear weapons. The sanctions largely prohibit high-tech exports to Iran and bar U.S. scientists from conducting research in Iran—or even providing advice—without a license from the U.S. Department of the Treasury. They prevent computers in Iran from downloading most scientific software, and the nation's disconnection from the international banking system makes it virtually impossible for Iranians to subscribe to overseas journals.

Yet Iran's synchrotron builders have pushed ahead. They have smuggled essential parts, built what they could not buy, and done without whenever possible. "Failure is not an option," says Javad Rahighi, a nuclear physicist and the ILSF's director. Animated by the same spirit, an array of other homegrown initiatives has flourished, despite the sanctions, in areas ranging from seismology to stem cell research. The result is a surprisingly robust scientific enterprise, as was evident when the Iranian government recently granted *Science* rare access to select facilities and researchers.

Iran's pariah status may soon be ending. In July, Iran and world powers signed a deal that should limit Iran's nuclear program and block its pathways toward a nuclear weapon in exchange for relief from economic sanctions. So long as U.S. and Iranian domestic politics don't interfere, implementation will begin by year's end.

Until sanctions are lifted, Western science engagement with Iran will proceed haltingly. But the pas de deux with the West is already underway. An Iranian delegation was in Vienna in July, striking agreements for joint research with the U.N. Industrial Development Organization and

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Iran is gearing up to build a national astronomy observatory with a 3.4-meter telescope here on the summit of Mount Gargash in central Iran.

other international partners. And earlier this summer, a group of U.S. university officials led by Allan Goodman, president of the Institute of International Education in New York City, traveled to Iran to assess where the United States and Iran might forge scientific ties. "We got a pretty consistent message that their science is alive and well," Goodman says.

THAT IS A TRIUMPH over the country's recent history, which is still on vivid display. At Behesht-e Zahra cemetery on the southern outskirts of Tehran, row upon row of graves, many marked by simple concrete slabs, stretch to the horizon. A vast section of the cemetery, one of the world's largest, is set aside for the troops—many of them teenage boys—who died during the Iran-Iraq War, a World War I–style conflict featuring trench warfare and poison gas attacks that lasted from 1980 to 1988. Images of the martyrs, as they are called, adorn bridges, billboards, and facades—a constant reminder of the hard years in the wake of the 1979 revolution that toppled the shah. The iconography "was an eye-opener for us," Goodman says. "We completely underestimated the profound effect that it's still having on Iranians."

For 3 years in the early 1980s, all Iranian universities were shuttered. Most able-bodied men were mobilized for the war—spurring a catastrophic brain drain. After the war was over, academia slowly clawed its way out of the abyss. Iran moved aggressively to bolster its higher education system, opening scores of new universities; student enrollment skyrocketed. As part of that revival, Sharif University of Technology (SUT) in Tehran launched the nation's first Ph.D. program, in physics. The government, meanwhile, started rolling out mission-oriented research centers, including one in Tehran for seismic risk now called the International Institute of Earthquake Engineering and Seismology (IIEES).

"We're entering the post-sanctions era," says Iran's deputy science minister Vahid Ahmadi. He's counting on Iran's diaspora to help his country's scientific community connect with the rest of the world.

PHOTO: EBRAHIM MIRMALEK

Seeking its own brand of postrevolution science, Iran's Supreme Council of the Cultural Revolution, established in the early 1980s to ensure that universities adhered to Islamic thought, launched Jihad-e Daneshgahi. Known in English as the Academic Center for Education, Culture and Research (ACECR), it aims to yoke science to societal needs. The center has funded practical efforts such as building high-voltage transmission lines and securing oil drilling equipment, and it teamed up with engineers in the city of Isfahan to make drones for Iran's military.

More improbably, ACECR has notched up an achievement in basic research. In 1991, it founded the Royan Institute in Tehran to help infertile Iranians, who until then had to travel abroad for treatment. (Royan is Farsi for "embryo" and "ever-growing.") The institute has since become a heavyweight in stem cell research, publishing hundreds of papers and scoring successes in animal cloning despite Iran's isolation.

On a grander scale, The Supreme Council aspired to set the pace for science in the Middle East. Its National Master Plan for Science and Education, released in 2011, lists as one objective "bolstering the promotion of science and technology in the Islamic world." According to the plan, the "revival of the great Islamic civilization" is "contingent upon all-out progress in science." The council set up an Islamic World Science Citation Center in Tehran in 2004, and it promoted Persian as an international scientific language. It even attempted to create an Islamic Internet.

By the early 2000s, Iran was thinking big in basic science, with planning underway for the ILSF and a world-class astronomical observatory (see sidebar, p. 1042). But the science push faced long odds. Iran was hemorrhaging talent, with many top students and scholars going abroad—and staying abroad. And science spending couldn't keep pace with the lofty ambitions. Although the official government target for science spending is 3% of gross domestic product, the reality is closer to 0.5%, which in 2014 amounted to $1.75 billion, says Vahid Ahmadi, Iran's deputy science minister and a specialist in optoelectronics. The science ministry, he says, controls only about 27% of that budget, he says. And that small pie is sliced thinly: Last year, SUT's research budget was only a few hundred thousand dollars, says Jawad Salehi, a professor of electrical engineering there. "90% of our papers are intellectual ideas. We don't have the budget to make prototypes," says Salehi, who worked for 10 years at Bellcore in Morristown, New Jersey. Compounding woes, take-home pay for scientists has withered because of the country's dire economic straits.

Faced with such penury, the scientific community was aghast in 2012 when the government of Mahmoud Ahmadinejad, a religious hardliner who served as Iran's president from 2005 to 2013, picked 40 projects for lavish support that over several years would amount to the science ministry's entire annual budget. "Most of those projects are suspect and would never pass real review," says a senior scientist in Tehran. Many awards went to political cronies of Ahmadinejad, critics contend.

But the biggest blow was the one Iran's government provoked from the world community. In 2002, Iranian dissidents revealed the existence of a secret uranium enrichment facility in Natanz. More revelations followed, prompting the United States and the United Nations to ratchet up sanctions. Stoking tensions, former U.S. President George W. Bush anointed Iran a member of his "axis of evil," whereas Ahmadinejad labeled the Holocaust a "myth" and Israel a cancer cell "that must be removed from the body."

AS THE PROHIBITIONS ON IRAN multiplied, they snared scientists along with the broader economy. For example, no stone can be imported from or exported to Iran—a ban meant to crimp the construction industry. "No stone means no fossils," says Erfan Khosravi, a paleontologist at the University of Tehran. "We can't borrow fossils to compare specimens or send fossils abroad for analysis," he says. And because radionuclide exports to Iran are barred, he says, "we can't date specimens."

Nor can Iranian scientists readily publish in international journals. Some editors reject Iranian submissions outright, claiming, wrongly, that reviewing a manuscript with any Iranian author would contravene sanctions. (Sanctions do bar U.S. citizens from reviewing work by an author from an Iranian government entity, such as its nuclear organization.) A few

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A female scientist in the Royan Institute's andrology lab. Women comprise more than half of Iran's workforce in the biological sciences.

years ago, after SUT was singled out for sanctions, Elsevier severed its agreement to publish the university's top journal, *Scientia Iranica*.

"The sanctions became so brutal," says IIEES President Mohammad Kazem Jafari. For years, the seismologist notes, his institute imported seismic sensors from Canada, the United Kingdom, and the United States; the accelerometers are deployed at faults to warn of nascent earthquakes and to monitor shaking and structural integrity at bridges, dams, and other vital infrastructure. Earthquake-wracked Iran needs such data, but such devices can also be used to monitor nuclear tests. Around 2010, Iran could no longer import seismic sensors, "even for humanitarian purposes," Jafari says.

His solution? Institute engineers designed their own sensor. In his office at IIEES, below a hazard map of Iran in which the entire country is crisscrossed with thick red lines depicting high seismic risk, Jafari cradles his institute's HAT accelerometer, a heavy black device resembling a child-size bowler hat. HAT sensors have been deployed, for instance, at Bushehr Nuclear Power Plant and the Hirvy dam in Kermanshah province, and in systems that would shut off Tehran's natural gas lines after a major earthquake.

"If something stops us, we find our way around it," geneticist Massoud Houshmand says. "We are like a river finding a new way." At the sprawling campus of the National Institute for Genetic Engineering and Biotechnology, Houshmand leads a team that can now diagnose more than 300 rare mitochondrial diseases, including some unique to Iran. He chalks up his success to his 50 current and former students now overseas who help his Tehran team carry out experiments.

Similar ingenuity is keeping Iran's synchrotron project on track. When preparatory work for the ILSF began at the Institute for Research in Fundamental Sciences (IPM) in 2010, the ILSF group knew they would not be able to import a key component, an ultrastable power supply for the machine's electromagnets. So they set out to make their own. "People laughed at us," Rahighi says. Five years later, the homegrown device works better than comparable equipment at some operating synchrotrons, he says. "People aren't laughing anymore."

When homespun resourcefulness fails, however, Iranian scientists have been forced to pay jacked-up prices on the black market, where smuggled instrumentation usually comes without service agreements. After the Iran Polymer and Petrochemical Institute here managed to lay hands on a first-rate nuclear magnetic resonance machine, the German manufacturer had a stark warning. "They said, 'You can send your parts for repair, but we cannot guarantee that we can send them back,'" says Director Mehdi Nekoomanesh.

And needed materials are often slow to arrive. That's especially aggravating when scientists are racing peers in a fast-moving field such as stem cell research. "Many times we've been scooped" because of sanction-related delays in tying up experimental loose ends, says Royan Institute President Hamid Gourabi.

NOW, IRANIAN SCIENTISTS ARE HOPING that the nuclear pact will bring changes: an opening to the West, a more benign political environment, and an improving economy that will allow more generous science funding. "It's a new era for science in Iran," Ahmadi says hopefully. "We're entering the postsanctions era."

The nuclear agreement calls for converting the Fordow uranium enrichment facility into an international research center, and designates cooperation in areas as diverse as fusion, astrophysics, and radiomedicine. IPM particle physicist Shahin Rouhani, president of the Physics Society of Iran, says Fordow's underground lab could host detectors for cosmic dark matter particles, and for neutrinos beamed through Earth from CERN, the European organization for nuclear research near Geneva.

Iran's entire scientific enterprise should benefit from the thaw. "By reintroducing the Iranian community as intellectual equals in the international scientific community, cultural understanding develops and bridges are built," says Gerry Gilmore, an

astronomer at the University of Cambridge in the United Kingdom, who serves on the international oversight committee for Iran's national observatory.

In what many take as a promising omen, Ali Brivanlou, the Iranian-born head of the laboratory of molecular embryology at The Rockefeller University in New York City, is due to arrive in Tehran this week for a lecture tour hosted by the Royan Institute. He expects an "extremely emotional" homecoming. Brivanlou was among the first wave of researchers to derive human embryonic stem cells (hESCs), and he made the seminal discovery that all embryonic cells will develop into nerve cells unless they receive signals directing them otherwise. Brivanlou had declined previous invitations because of the tensions over Iran's nuclear program. But the agreement changed his mind—as did his respect for the science at Royan.

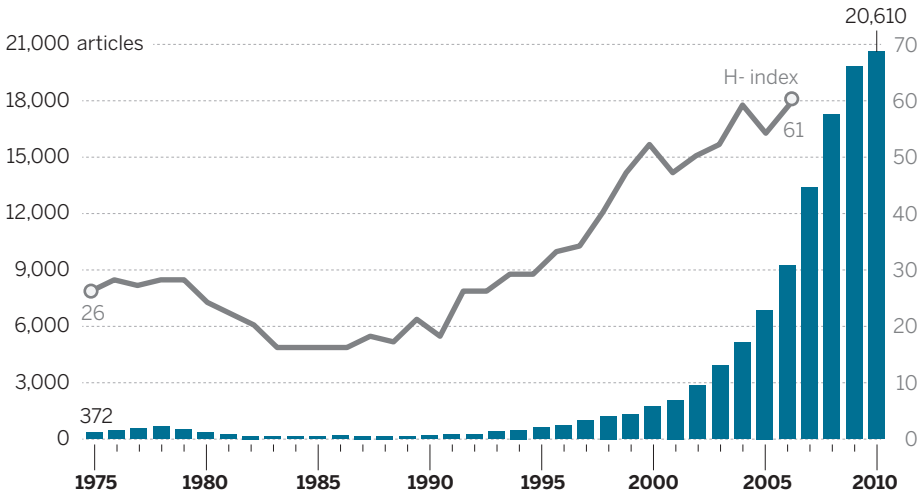
"Surprisingly, Iran has some of the most liberal laws on stem cell research in the world," Brivanlou says, thanks to a 2002 fatwa from Iran's Supreme Leader Seyyed Ali Khamenei declaring such research permissible under Islamic law. (Reproductive cloning in humans is out of bounds.) Royan established its first hESC line, Royan H1, in 2003 and has performed more than 40 clinical trials with stem cell transplantation.

Royan researchers were the first in the Middle East to succeed in somatic cell cloning—a lamb in 2006—and last month they scored another first when they cloned a mouflon, an endangered species of wild sheep. Royan is also a participant in the international Human Proteome Project: It is responsible for characterizing all of the proteins coded by the Y chromosome.

"We are a small flower," Royan Director Hossein Baharvand says of his institute, which is filled with female researchers. (Nationwide, about half of the scientific workforce is women.) Yet Brivanlou is impressed with what they have accomplished. "They're on par with Western European and U.S. labs," he says. "The papers they produce are extremely high quality." Still, Royan scientists are unable to perform many experiments that are routine in the West, says Rudolf Jaenisch, a stem cell researcher at the Whitehead Institute for Biomedical Research in Cambridge, Massachusetts, who visited Royan in 2007 and 2010. "It was sad to see the consequences of the embargo on their work."

A rising science power

Even while laboring under sanctions, Iran has aspired to set the pace for science in the Middle East. In journals indexed by the Web of Science, the articles from Iran are skyrocketing, as is its H-index, a metric for productivity and citation impact.



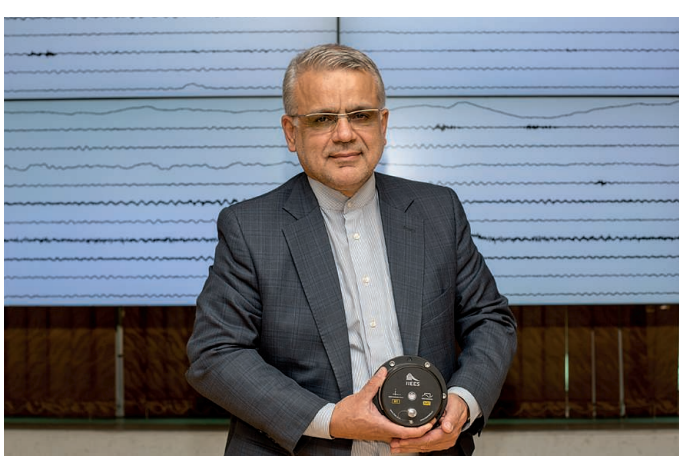
IRAN'S SCIENCE ESTABLISHMENT hopes that ties with Brivanlou and other Iranians who have made their mark abroad will help elevate research at home. "Policymakers are very keen to collaborate with overseas Iranian scientists and engineers," says Mohammad Abooyee, director of the National Research Institute for Science Policy in Tehran. The science ministry is stepping up efforts to sponsor overseas Iranians on short-term visits to Iran. And the government is drawing up plans for a more ambitious program to entice expats to accept permanent positions, Abooyee says. "It is time for them to come home."

To attract Iranians now working in the West, Iran will have to bolster both funding and academic freedom. Optimists see glimmers of progress on both fronts. This summer the government upped the budget of the National Elites Foundation, which hands out research grants to top scientists and enables elite science postgrads to spend 2 years on a research project in lieu of mandatory military service. And in October 2013, 3 months after being sworn in as Iran's president, Hassan Rouhani called on his nation's intelligence ministry to relax its scrutiny of academia "so all faculty members would feel safe to express themselves and participate in debates on campus."

"Resistance to change is deep rooted in our culture," says a senior science policy analyst in Iran. But "little by little," he says, "hardliners are being pushed to the side."

Rahighi returned to Iran in 1986—long before it was fashionable for expats to come home—after a stint in Europe using radioactive ion beams to study the nuclear reactions inside stars. He joined the Atomic Energy Organization of Iran, but says he bailed out of the nuclear program to head up the ILSF. "I've kept this project very transparent from the beginning," he says. That's good, says Attwood, who emphasizes that Iran "will need help to build this thing."

Rahighi is counting on it. The ISLF "will be a place where we can meet with the West," he says. He pictures his machine not just as an x-ray source—but also as a citadel of basic research in a transformed scientific landscape. ■



As sanctions tightened, Iran's seismology institute could no longer import seismic sensors. Director Mohammad Kazem Jafari cradles a homemade version.

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