INSTITUTE FOR SCIENCE AND INTERNATIONAL SECURITY

REPORT

A Technical and Policy Note on Iran's Recent Uranium Enrichment Capacity Claims

An Annex summarizes the status of Iran's enrichment program, based on the last quarterly report of the International Atomic Energy Agency (IAEA)

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On April 8, 2020, one day before Iran's Nuclear Technology Day, a spokesperson for the Iranian Atomic Energy Organization (IAEO) announced that Iran could produce 60 "advanced" centrifuges a day, with the goal to reach an enrichment capacity of 250,000 separative work units (swu) per year, ultimately one million swu per year.[1] It is unlikely, for several reasons, that Iran will reach this capacity with its existing advanced centrifuges for many years, if ever. Currently, its enrichment capacity is about 7500 swu per year (see Annex). This capacity represents a growth of about 20 percent since November 2019 with almost three quarters of that capacity invested in first generation IR-1 centrifuges, the rest in a mélange of advanced centrifuges. To reach 250,000 swu per year, Iran would need to increase its current enrichment capacity 30-fold, entailing the installation and operation of tens of thousands of advanced centrifuges. This goal seems out of Iran's reach, faced with advanced centrifuges that rarely work as planned and often fail, with a chaotic program that appears to be developing far too many centrifuges, all at best mediocre and poorly performing, and with little chance of ever competing economically with Russian and European centrifuges that supply most of the enrichment needs of nuclear power reactors in the world, including Iran's own Bushehr reactor.

However, this bluff pays dividends for expanding a nuclear weapons capability; such an official "civilian" aim serves as a cover story for ramping up domestic centrifuge production and enrichment capacity. Even if Iran fails to reach the 250,000 swu per year, as expected, its enrichment capacity could become sufficient at even less than one-tenth that number for relatively short breakout time to produce weapon-grade uranium, a key nuclear explosive material.

Such a large centrifuge production capacity would also make it easier to hide centrifuges, deploying them later at an opportune time in clandestine centrifuge plants, shortening breakout times further as well as complicating knowing where breakout is occurring.

[1] ISNA News Agency, April 8, 2020 (in Farsi). We wish to thank William Broad at *The New York Times* for pointing out this media report.

Iran's Statement is a Bluff

An annual 250,000 swu enrichment capacity can produce enough enriched uranium needed to fuel annually about two commercial nuclear power reactors of the size of the existing Bushehr reactor, this capacity being a minimum size of a modern, civilian enrichment program. A rate of 60 centrifuges per day works out to 21,900 centrifuges a year, assuming production every day of the year. This number appears very high; it goes without saying that Iran is likely exaggerating the rate, but there are several other issues that undermine such an annual production of functioning, reliable centrifuges, able to lead to an enrichment capacity of 250,000 swu per year.

- Iran's advanced centrifuges have not achieved enrichment capacities much above 5 swu/year per machine, making it necessary to build many tens of thousands of them to reach 250,000 swu/year. At 5 swu/year/machine, Iran would need to deploy 50,000 centrifuges to reach that capacity. Its IR-8 was supposed to reach a value of over 10 swu/year, but this centrifuge has been a failure. Any claims about an IR-9 are likely bluster. Its IR-6, which had a measured single-machine capacity of less than 7 swu per year, is still under development, although Iran is concentrating on its family of IR-6 centrifuges at the Pilot Fuel Enrichment Plant (see Annex). One of these may emerge as Iran's advanced centrifuge of choice but likely with an average output far below 10 swu/year when operating in production-scale cascades.

- Based on Iran's history of building and operating centrifuges, many of its centrifuges do not meet quality assurance standards, or they fail in pre-operational tests or during operation in cascades. The failure rates of the IR-1 and IR-2m centrifuges at Natanz have been recorded by the IAEA as 20 percent or higher per year.

- Iran's centrifuges require raw materials, some are sensitive and not made by Iran, such as carbon fiber. For example, all its advanced centrifuges have rotors made from carbon fiber. Sanctions would make it very difficult for Iran to acquire enough carbon fiber to produce 60 advanced centrifuges a day on a sustained basis. Its IR-2m needs maraging steel in its bellows, a high strength, specialized subcomponent connecting rotor tubes, requiring another sensitive, controlled raw material Iran does not make and thus necessitating illicit procurements of enough maraging steel from abroad to make tens of thousands of centrifuges.

The Danger of Iran's Enrichment Program

Bluffing about reaching this large capacity helps Iran counter the arguments of those that call for a shut-down of its enrichment program for one reason: it will never be economically viable. In the meantime, Iran can use this public goal to hide a growing centrifuge program that would powerfully expand its nuclear weapons breakout capabilities, if implemented.

Breakout times would shorten drastically. Despite their problems, Iran's advanced centrifuges offer a clear advantage over its existing IR-1 centrifuge, each one providing four to over six times the enrichment output of a single IR-1 centrifuge.

Ramped up advanced centrifuge manufacturing also increases the risk of undetected clandestine production of centrifuges and a secret enrichment plant. This risk can increase even under IAEA monitoring, if critical centrifuge production materials and equipment are not under strict supervision. Just recently, the IAEA reported in its latest quarterly reports on an on-going violation of the monitoring of carbon fiber, a warning that has attracted little response.[2] On February 17, 2020, the IAEA "verified that Iran was continuing to manufacture centrifuge rotor tubes using carbon fibre that was not subject to continuous Agency [IAEA] containment and surveillance measures," as required by the JCPOA and a decision of the Joint Commission of January 14, 2016 (see INFCIRC/907).[3] Iran is known to be able to obtain illicitly supplies of carbon fiber and other sensitive goods for centrifuge manufacturing and appears to be using some of these ill-gotten goods in manufacturing advanced centrifuges. Despite some successes, Iran is often thwarted in its attempts to obtain carbon fiber abroad,[4] making it unlikely that it could smuggle enough to sustain a manufacturing rate of 60 centrifuges per day. However, as in the case of separative output, Iran could likely smuggle enough carbon fiber to build many thousands of advanced centrifuges and achieve relatively low breakout timelines. Moreover, smuggled carbon fiber could be used in a parallel, secret centrifuge manufacturing plant to make centrifuges for a clandestine centrifuge plant. To mitigate this risk, IAEA access to any site in Iran is crucial, a necessity and an IAEA right that has never been achieved, with or without the Joint Comprehensive Plan of Action (JCPOA).

It is time to end this charade that somehow Iran's centrifuge program is justified, or somehow legitimized by the JCPOA. For those in Iran and elsewhere who believe that its nuclear program is peaceful, abandoning enrichment voluntarily is the only sensible economic course of action, an act that would also go far in ending Iran's current economic and political isolation. Given a hugely uneconomic centrifuge program, one posing an unacceptable security risk to the region and the world and spurring other countries to proliferate, the international community's most sensible option is to insist that Iran end its uranium enrichment program.

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[2] IAEA Director General, *Verification and monitoring in the Islamic Republic of Iran in light of United Nations Security Council resolution 2231 (2015)*, GOV/2020/5, March 3, 2020, https://isis-online.org/uploads/iaea-reports/documents/IAEA_quarterly_Iran_report_February_2020.pdf

[3] Relevant clauses from INFCIRC/907: "Template for Describing Centrifuge Types: Explanatory Note,"
II(3)(e)(v). The IAEA would verify that Iran only engages in manufacturing of centrifuge rotor tubes using the material that are drawn from the above referenced dedicated monitored storage locations for as long as Paragraph 61 of the Annex 1 of the JCPOA remains in effect, subject to the exception specified below.
II(3)(e)(v). Despite the readiness of supply, Iran may decide, consistent with the JCPOA, to manufacture centrifuge rotor tubes using its own materials of construction, provided that the IAEA has verified the technical specifications of these materials through sampling and maintained them under monitoring until their use in the manufacture of rotor tubes.

[4] David Albright, Sarah Burkhard, Spencer Faragasso, Linda Keenan, and Andrea Stricker, *Illicit Trade Networks - Connecting the Dots, Volume 1* (Washington, D.C.: Institute for Science and International Security, 2020), https://isis-online.org/books/detail/illicit-trade-networks-connecting-the-dots-volume-1

Annex Status of Iran's Enrichment Capacity as of March 2020, based on the International Atomic Energy Agency's Quarterly Report on Iran

This annex summarizes and assesses the reporting in the IAEA's March 3, 2020 quarterly report, *Verification and monitoring in the Islamic Republic of Iran in light of United Nations Security Council resolution 2231 (2015)*.[5]

IR-1 Centrifuge Deployments at Natanz Fuel Enrichment Plant (FEP)

At the Natanz Fuel Enrichment Plant, the International Atomic Energy Agency (IAEA) reported in its last quarterly report that Iran operated no more than 5060 IR-1 centrifuges in 30 cascades. Iran withdrew 92 IR-1 centrifuges from storage to replace broken ones in these cascades. During the previous reporting period, it withdrew 48 IR-1 centrifuges, and during the prior one, it withdrew 18 IR-1 centrifuges. The large jump in the replacement number likely reflects the stepped-up production of enriched uranium and consequent centrifuge breakage that plagues IR-1 centrifuges.

Fordow Fuel Enrichment Plant (FFEP)

The IAEA reported that as of January 22, 2020, the Fordow plant was enriching uranium in six cascades, containing 1044 IR-1 centrifuges, in one wing of the plant, called Unit 2. An additional 13 IR-1 centrifuges were installed in Unit 2, all of them involved in initial research and development activities related to stable isotope production.

Iran has rendered defunct the JCPOA's provision that the Fordow plant be converted to a nuclear, physics, and technology research center. A senior Iranian official emphasized that reality, stating on November 9, 2019, "In fact, we can say that we have abandoned a number of clauses of the JCPOA, including the 44th, which stipulates that Fordow should be transformed into an international nuclear and physical center."[6] Iran has also been actively creating a domestic nuclear equipment production plant at nearby Fordow support facilities.[7]

Advanced Centrifuges

Iran continued to take steps during this IAEA reporting period to violate the JCPOA's limitations on advanced centrifuges. The following summarizes the deployment of advanced centrifuges in

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[5] IAEA Director General, *Verification and monitoring in the Islamic Republic of Iran in light of United Nations Security Council resolution 2231 (2015)*, GOV/2020/5, March 3, 2020, https://isis-online.org/uploads/iaea-reports/documents/IAEA_quarterly_Iran_report_February_2020.pdf

[6] "Iran May Reject Modernisation of Arak Reactor: Atomic Energy Organisation," *Sputnik*, November 9, 2019, https://english.almanar.com.lb/866824

[7] David Albright, Sarah Burkhard, Frank Pabian, and Jack Toole, "Conversion of Fordow: Another Unfulfilled Hope of the Iran Nuclear Deal," *Institute for Science and International Security*, July 10, 2019, https://isis-online.org/isis-reports/detail/conversion-of-fordow-another-unfulfilled-hope-of-the-iran-nuclear-deal

the six lines at the Natanz Pilot Fuel Enrichment Plant (PFEP), their enrichment status, and their enrichment capacity, if known, as of the end of the last IAEA reporting period.

Iran is no longer remixing the product and tails (waste), but collecting it separately, meaning that Iran accumulates enriched uranium at the PFEP. As of February 19, 2020, 268.5 kilograms (uranium mass) of uranium enriched up to two percent had been collected from lines 2 and 3 of the six lines at the PFEP. The IAEA does not provide the average enrichment of this material, although it can be safely assumed that it varies from just above natural uranium (0.71% uranium 235) up to 2% uranium 235. (This average value matters because the amount of separative work to make, for example, a quantity of two percent enriched uranium is several times the amount to make that quantity of one percent enriched uranium.) The IAEA did not reveal how much enriched uranium was collected in the other lines of the PFEP.

Lines 2 and 3 contained a variety of centrifuge types and numbers, many accumulating enriched uranium. The following is a summary, as of the end of the last reporting period, of all the centrifuges installed in lines 2 and 3, or about 100 in total, that were accumulating enriched uranium (so far about 268.5 kg, as mentioned above):

1. Up to 20 IR-2m centrifuges in a cascade;
2. Up to 20 IR-4 centrifuges in a cascade;
3. Up to 10 IR-5 centrifuges in a cascade;
4. Up to 30 IR-6 centrifuges, in a centrifuge cascade of 10 IR-6 centrifuges and another one of 20 IR-6 centrifuges;
5. Up to 20 IR-6s centrifuges in cascades

According to the IAEA report, the following single centrifuges were being tested with uranium hexafluoride in lines 2 and 3 but not accumulating enriched uranium:

1. two IR-2m centrifuges;
2. one IR-3 centrifuge;
3. one IR-4 centrifuge;
4. one IR-5 centrifuge;
5. one IR-6 centrifuge;
6. one IR-6m centrifuge;
7. one IR-6s centrifuges;
8. one IR-6sm centrifuge;
9. two IR-7 centrifuges;
10. two IR-8 centrifuges;
11. one IR-8s centrifuge;
12. one IR-8B centrifuge;
13. one IR-s centrifuge; and
14. one IR-9 centrifuge.

Iran also accumulated enriched uranium in lines 4, 5, and 6, in redeployed IR-2m and IR-4 centrifuge cascades (164 centrifuges each) and an IR-6 cascade (72 centrifuges), although the IAEA did not specify how much enriched uranium had been produced so far, or its level of enrichment. It is possible that this enriched uranium is included in the IAEA's aggregate, reported amount of enriched uranium enriched up to 4.5 percent.

The redeployed 164 IR-2m and IR-4 centrifuge cascades in lines 4 and 5 of the PFEP represent Iran's most successful advanced centrifuge types. When previously operated in a production-scale cascade, each IR-2m centrifuge had an enrichment capacity of about 3.7 SWU per year. The total cascade thus has an estimated enrichment capacity of about 607 SWU per year. This is equivalent to about 675 IR-1 centrifuges operating in production cascades, where each IR-1 is assumed to have a capacity of 0.9 SWU per year. The IR-4 has a lower capacity than the IR-2m, estimated here as ten percent lower, or about 3.3 SWU per year per centrifuge. The production cascade would have a total output of about 540 SWU per year, or equivalent to about 600 IR-1 centrifuges. These two cascades represent a total capacity of about 1,147 SWU/year, or the equivalent of about 1,275 IR-1 centrifuges.

Line 6 at the PFEP held 72 IR-6 centrifuges in a single cascade. Iran stated earlier that the line will hold 164 IR-6 centrifuges in a cascade.[8] The IR-6 has a single machine estimated capacity of 6.8 SWU per year. No recent data are available publicly on its performance in this cascade. Assuming that the cascade value would be about 90 percent of the capacity achieved by an IR-6 operating by itself, 72 IR-6 centrifuges in cascade would have an output of about 441 SWU per year, and a cascade of 164 IR-6 would have total capacity of about 1,000 SWU per year, or the equivalent of about 1,115 IR-1 centrifuges.

Line 1 holds an inoperable cascade of IR-1 centrifuges. In addition, according to the quarterly IAEA report, "On 7 January 2020, the Agency verified that, for eight days, Iran had conducted mechanical testing of eight IR-6 centrifuges simultaneously – two at the Tehran Research Centre and six at a workshop in Natanz."

As can be seen, Iran is developing a large number of centrifuges simultaneously, an unusual practice. The centrifuges at the PFEP include: IR-1, IR-2m, IR-3, IR-4, IR-5, IR-6, IR-6m, IR-6s, IR-6sm, IR-7, IR-8, IR-8s, IR-8B, IR-s, and IR-9. No information was provided in the IAEA report on how well these centrifuges work, their failure rates, or why so many of them are being developed. Typically, a centrifuge program with such characteristics is likely failing at developing a commercially viable centrifuge, although several of these centrifuges could work adequately in a nuclear weapons program, where efficiency, low failure rates, and low cost are not priorities.

[8] IAEA Acting Director General, *Verification and monitoring in the Islamic Republic of Iran in light of United Nations Security Council resolution 2231 (2015),* GOV/INF/2019/12, September 26, 2019, https://www.iaea.org/sites/default/files/19/11/govinf2019-12.pdf

Enrichment Capacity

Iran continues to increase its enrichment capacity and gain additional experience in operating advanced centrifuges. While the former is reversible, the latter is not. This knowledge and experience cannot be lost. Table A.1 summarizes the enrichment capacity by facility. Iran's enrichment capacity has grown from an estimated 6200 swu/yr to 7492 swu/yr during this reporting period, representing a growth of about 21 percent.[9]

Table A.1. Number of Centrifuges Enriching and Total Enrichment Capacity

Location	Number of Centrifuges	Enrichment Capacity (SWU/yr)
Natanz FEP	5060 IR-1	4554
Fordow FEP	1044 IR-1	940
Natanz PFEP (advanced)*		
Lines 2 and 3	see text	~410
Lines 4, 5, 6	see text	1588
	Total:	**7492**

*The value for lines 2 and 3 of the PFEP is a rough estimate based on the use of estimated and measured values for the separative output of these centrifuges in cascades, drawn from IAEA information. The values for lines 4, 5, and 6 of the PFEP are given in the text. All of the values used to make these estimates reflect historical enrichment output values obtained by Iran prior to the nuclear deal and do not reflect current values, which are not included in the IAEA's quarterly reports.

[9]David Albright and Andrea Stricker, "IAEA Iran Safeguards Report Analysis - Iran Commits Multiple Violations of the Nuclear Deal, Several Non-Reversible," *Institute for Science and International Security*, November 13, 2019. https://isis-online.org/isis-reports/detail/iaea-iran-safeguards-report-analysis/8