INSTITUTE FOR SCIENCE AND INTERNATIONAL SECURITY

Updated Highlights of Comprehensive Survey of Iran's Advanced Centrifuges[1]

By David Albright, Sarah Burkhard, and Spencer Faragasso

June 13, 2022

Photo Credit: Iran's AFTAB News

[1] David Albright, Sarah Burkhard, and Spencer Faragasso, "A Comprehensive Survey of Iran's Advanced Centrifuges," *Institute for Science and International Security*, December 2, 2021, https://isis-online.org/isis-reports/detail/a-comprehensive-survey-of-irans-advanced-centrifuges/8.

440 First Street NW, Suite 800, Washington, DC 20001
TEL 202.547.3633 Twitter @TheGoodISIS
Subscribe to mailer here. | E-MAIL isis@isis-online.org | www.isis-online.org

Advanced Centrifuge Deployments

In the last two and a half years, Iran has been deploying advanced centrifuges in violation of the limits in the Joint Comprehensive Plan of Action (JCPOA), following a lull of three years created by those limits. Starting in late 2020 or early 2021, it dramatically increased the number of deployed advanced centrifuges. Iran has demonstrated its commitment to replace the IR-1 centrifuge with advanced centrifuges, which can produce considerably more enriched uranium.

Iran has been deploying advanced centrifuges at three enrichment plants–the Natanz above-ground Pilot Fuel Enrichment Plant (PFEP), and the much bigger, below-ground Fuel Enrichment Plant (FEP), and the deeply buried Fordow Fuel Enrichment Plant (FFEP). Iran's deployments have been less than expected based on Iran's official plans, but Iran continues to express its intention to accelerate them, particularly deployments of the IR-4 and IR-6 centrifuges.

Figure H.1 shows the number of advanced centrifuges deployed from 2011 onwards through May 2022, with a projection for late 2022 based on Iran's announced plans. Despite the increases in 2021, it is now apparent that Iran's recent deployments of advanced centrifuges have been slower than planned. In fact, the number of deployed advanced centrifuges did not increase in the last three months.

One likely cause is the destruction of the Natanz Iran Centrifuge Assembly Center (ICAC) and a centrifuge manufacturing plant at a site called TABA Karaj (also known as TESA), situated near Karaj. The ICAC was built to have a capacity to make a few to several thousand advanced centrifuges per year. Iran's subsequent manufacturing and assembly capacity appears to have been substantially reduced, down to a level of several hundred advanced centrifuges per year. Its temporary assembly facility, inaugurated at Natanz in April 2021, about 9 months after the attack on the ICAC, has failed to compensate for the destruction. Shortly after this inauguration, an attack on Iran's centrifuge manufacturing capabilities at Karaj likely delayed production of centrifuges further. The subsequent, recent moving of manufacturing capabilities to Natanz further contributed to production delays.

Despite these delays, considering Iran's ongoing commitment to earlier announced plans, as well as recent affirmation of its determination to increase the number of installed advanced centrifuges, Iran will likely accelerate installation of advanced centrifuges, albeit at a slower rate than it could have without the destruction of these two facilities.

As it does so, uncertainties will likely grow in the estimated number of advanced centrifuges produced in excess of those deployed, adding concern to the possibility that Iran will again seek to build a clandestine enrichment plant, using advanced centrifuges manufactured in secret. Iran was stymied by Western pressure in the 2000s from secretly building an underground enrichment plant at Qom (now called Fordow) to make weapon-grade uranium. Today, it could revitalize that plan, moving to build an enrichment plant with 1000 IR-6 centrifuges, achieving significantly more enrichment output in a smaller space than Fordow with its planned 3000 IR-1 centrifuges.

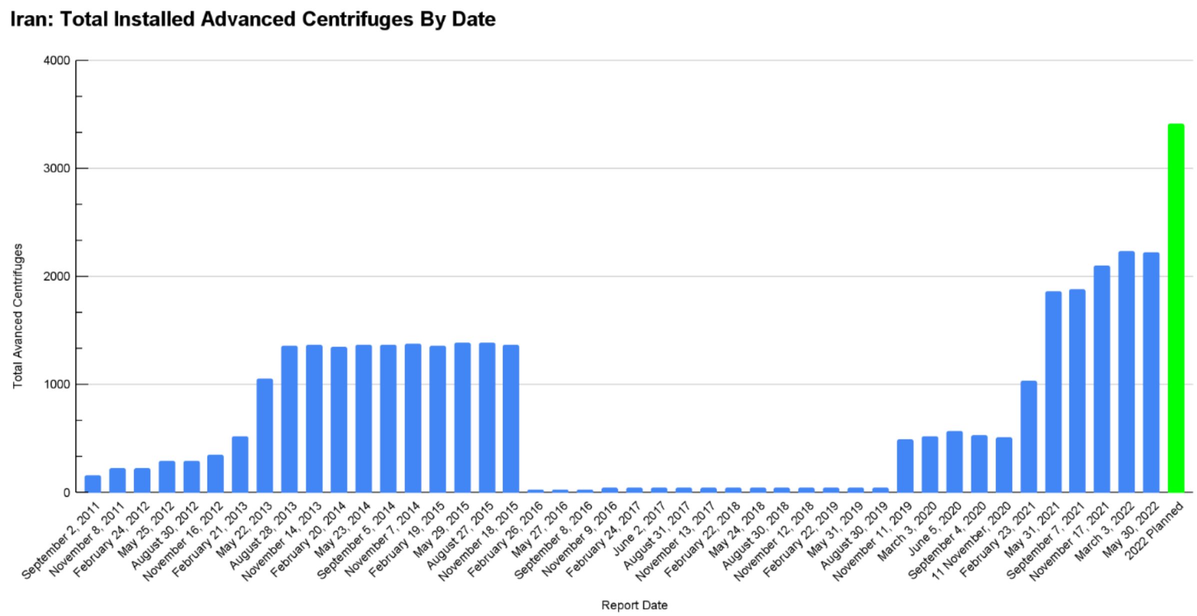


Figure H.1. Iran's quarterly number of installed advanced centrifuges at its three enrichment plants, with a multi-quarter projection late-2022 (last vertical bar). (The number of IR-1 centrifuges are ignored in this graph but see Figure H.3 for a complete breakdown of the situation today.) In April 2021, the Natanz FEP was attacked, affecting half of the IR-2m and IR-1 cascades. The total number of installed cascades remained the same but many of the centrifuges could have been destroyed. Since the attack, Iran likely replaced the broken centrifuges in those cascades, although the IAEA does not report how many centrifuges were replaced.

A Closer Look at the Numbers

Figure H.1 shows a steady increase in the number of advanced centrifuges until 2013, followed by a plateau, and then a sharp drop in 2016, when the JCPOA was implemented with a focus on limiting advanced centrifuge research and development, at least temporarily. That number started to increase again in the fall of 2019, after Iran began to violate the JCPOA, but at a faster rate than prior to the JCPOA, reaching unprecedented deployment levels in May 2021 after a sharp increase after late 2020. For a year now, the number of deployed advanced centrifuges has exceeded the number deployed prior to the JCPOA. As of September 2021, Iran had approximately 1889 advanced centrifuges installed at its three enrichment plants. By mid-November 2021, this number increased to 2101. By the end of February 2022, this number reached 2232. Until the end of May 2022, this number remained constant at 2228. The decrease of four advanced centrifuges reflects negligible changes at the PFEP.

Since August 2019, Iran has installed 2183 advanced centrifuges, including redeploying IR-2m, IR-4, and a variety of other advanced centrifuges put in storage during the JCPOA. In order to estimate a rate of manufacturing and assembly, the centrifuges installed prior to the JCPOA need to be subtracted from the total of 2183. Subtracting that number results in 864 new advanced centrifuges installed since August 2019 and likely manufactured after 2018. On average, Iran has installed 25.4 new advanced centrifuges per month, or 305 per year. This average is likely a minimal estimate, since Iran also has to make advanced centrifuges to replace already installed ones that break.

Iran has reiterated its determination to increase the number of deployed advanced centrifuges over the next several months. The IAEA confirmed in its May 2022 quarterly report that Iran was in the process of installing an additional cascade of IR-4 centrifuges at the Natanz FEP.[2] In early June 2022, Iran told the IAEA it was also installing one IR-6 cascade at the Natanz FEP, a step announced months ago, and in a new development, that it plans to install two additional IR-6 centrifuge cascades at the FEP, for a total of three IR-6 centrifuge cascades at the FEP.[3] If all three IR-6 cascades are installed, Iran will have a total of six production-scale IR-6 cascades installed across the three enrichment plants at Natanz and Fordow and a total of 1030 IR-6 installed centrifuges in those plants, a number in line with its national nuclear law dating to December 2020, mandating the installation of 1000 IR-6 centrifuges.

Based on Iran's declarations to the IAEA and the December 2020 legislation, the Atomic Energy Organization of Iran (AEOI) plans to install up to another 1200 advanced centrifuges, bringing the projected total to about 3400 installed advanced centrifuges. Despite Iran's recent announcements about additional deployments of IR-4 and IR-6 centrifuges, achieving this number at the three existing centrifuge plants looks increasingly unlikely in 2022.

Iran is trying to recover from the attacks at Natanz and Karaj. It has successfully established small scale centrifuge manufacturing and assembly facilities at Natanz. It continues building a large, replacement centrifuge assembly facility under a mountain south of the FEP, which may be ready for initial operation by the end of 2022.[4] As a result, over a longer period of time, Iran may be able to deploy the projected number of advanced centrifuges and further increase centrifuge installation as the facility under the mountain comes into full operation, likely with a capacity to assemble thousands of advanced centrifuges per year.

In the meantime, by March 2022, Iran had already achieved its goal of installing six additional cascades of IR-1 centrifuges at the Natanz FEP, resulting in a total of 42 IR-1 cascades across its enrichment plants (36 cascades at Natanz and six cascades at Fordow). Although Iran has thousands of IR-1 centrifuges in storage it can draw from, this achievement shows Iran is

---

[2] "Analysis of IAEA Iran Verification and Monitoring Report - May 2022," *Institute for Science and International Security*, June 6, 2022, https://isis-online.org/isis-reports/detail/analysis-of-iaea-iran-verification-and-monitoring-report-may-2022.

[3] Francois Murphy, "Exclusive: Iran expands advanced centrifuge work underground, IAEA report shows," June 8, 2022, Reuters, https://www.reuters.com/world/middle-east/iran-expands-advanced-centrifuge-work-underground-plant-iaea-says-2022-06-08/.

[4] David Albright and Sarah Burkhard, "Imagery Update: Iran Continues to Harden its New Natanz Tunnel Complex," *Institute for Science and International Security*, May 5, 2022, https://isis-online.org/isis-reports/detail/imagery-update-iran-continues-to-harden-its-new-natanz-tunnel-complex-2022/8.

actively working on implementing its plans previously submitted to the IAEA, where the IR-1 cascades are likely taken from those dismantled and mothballed under the JCPOA.

Key Production-Scale Advanced Centrifuges: IR-2m, IR-4, and IR-6 Centrifuges

The most important advanced centrifuges today are the IR-2m, IR-4, and IR-6 centrifuges. The recent deployments represent a build-*back* for the IR-2m centrifuge, in contrast to a build-*up* for the IR-4 and the IR-6 centrifuges.

One way to see the importance of these three centrifuges is to consider that they can replace the IR-1 centrifuges while utilizing the same existing cascade piping and feed and withdrawal systems at the Natanz and Fordow sites. In terms of wide-scale deployments, the IR-4 and IR-6 centrifuges appear more important than the IR-2m centrifuge.

Notably, when Iran started production of 60 percent highly enriched uranium in April 2021, the IR-4 and IR-6 centrifuges were chosen for this task, rather than the ones with which Iran had more operational experience, such as the IR-1 or IR-2m centrifuge. The IR-1 centrifuge has already been used for the production of 20 percent enriched uranium, and the IR-2m centrifuge has been operated in cascades for several years. Further, when choosing to install a cascade at Fordow with sub-headers easily modifiable for producing different levels of enrichment, Iran chose the IR-6 centrifuge.

In terms of understanding the impact of these three centrifuges, a key value is their estimated average enrichment output when arranged into cascades of about 160-170 centrifuges, called production-scale cascades, the workhorse for enrichment in Iran. These estimated average outputs are less than theoretical values or single centrifuge measured values because of inefficiencies experienced during larger-scale cascade operation. The enrichment output of the IR-2m centrifuge when operating in a production-scale cascade is estimated in the main report (*A Comprehensive Survey of Iran's Advanced Centrifuges*, December 2021, available here) at 3.67 SWU per year; the estimated value for the IR-4 centrifuge in a production-scale cascade is 3.3 SWU per year. The equivalent value for the IR-6 centrifuge is harder to discern from the available information, but an estimated value of approximately 5.25 SWU per year appears justified and reasonable for its average output in a production-scale cascade. In general, these more practical outputs are about 75 percent of their single machine theoretical values given in the main report.[5] In practice, lower average values result due to centrifuge breakage, inefficient operation, or during the production of highly enriched uranium, such as production of 60 percent enriched uranium or weapon-grade uranium. Nonetheless, the practical enrichment output of these three centrifuges is far higher than that of the IR-1 centrifuge, which has achieved average production-scale cascade values of 0.6-1.0 SWU per year per centrifuge.

[5] As discussed in the main report, the associated single machine theoretical values for the IR-2m, IR-4, and IR-6 centrifuges are 4.4, 4.7, and 6.7 SWU/year/centrifuge, respectively. For comparison the single machine theoretical value for the IR-1 centrifuge is 1.4 SWU/year/centrifuge.

Table H.1 Enrichment Output of Iran's Key Advanced Centrifuges

Type	Average Enrichment Output in Production-Scale Cascade (SWU/year/machine)
IR-2m	3.67
IR-4	3.3
IR-6	5.25 (estimated)

Note: The enrichment output unit in this table should not be confused with Iran's non-standard enrichment output unit (called in the main report the uranium hexafluoride unit).

Advanced Centrifuge Development and Status

Figure H.2 is a timeline of the deployment of major advanced centrifuge types; the horizontal axis gives the year in which each type was deployed for the first time at the pilot plant at Natanz, starting with the IR-2 and IR-3 centrifuges in 2008. For comparison purposes, the vertical axis lists each centrifuge's theoretical enrichment output, the only value available for all centrifuge types. It should be noted that, when data exist, the output in practice, particularly in production-scale cascades, has proven to be significantly less than predicted by these theoretical values. Some centrifuge types are not included in Figure H.2; these centrifuges are included in Chapter 1 of the main report, along with a more detailed discussion about the theoretical and achieved enrichment outputs of each centrifuge type.

Starting in November 2019, Iran demonstrated that it had accelerated its centrifuge research and development by installing seven types of advanced centrifuges in addition to the existing seven types allowed under the JCPOA. These seven additional types were not included in Iran's confidential JCPOA enrichment plan, which projected the deployment of centrifuges up to about 2030.[6] The seven allowed ones are the IR-2m, IR-4, IR-5, IR-6, IR-6s, IR-7, and IR-8 centrifuges. The seven not allowed to be deployed under the JCPOA are the IR-3, IR-s, IR-6M, IR-6sm, IR-8B, IR-8s, and IR-9 centrifuges. Of these, all but the IR-3 centrifuge are new models.

Iran's rapid deployment of advanced centrifuges in 2019, including many new models, suggests that centrifuge development work continued during the JCPOA period from 2016-2018 and accelerated secretly as soon as the United States ended its participation in the JCPOA in May 2018. For example, some of Iran's IR-6 centrifuges started using domed instead of flat endcaps. By early 2021, Iran was testing steel bellows strengthened with carbon fiber for the IR-6 instead of carbon fiber bellows, perhaps indicating ongoing problems in those bellows.[7]

---

[6] "Iran's Long-Term Centrifuge Enrichment Plan: Providing Needed Transparency," *Institute for Science and International Security*, Re-released April 25, 2019; Originally issued August 2, 2016, https://isis-online.org/isis-reports/detail/irans-long-term-centrifuge-enrichment-plan-providing-needed-transparency/8.
[7] "Analysis of IAEA Iran Verification and Monitoring Report - February 2021," *Institute for Science and International Security, February 25, 2021,* https://isis-online.org/isis-reports/detail/analysis-of-iaea-iran-verification-and-monitoring-report-February-2021/8.

Of the fifteen advanced centrifuge types in Figure H.2, based on the May 2022 quarterly IAEA report, the IR-2m, IR-4, IR-5, IR-6, IR-6s, and IR-s centrifuges were accumulating enriched uranium. The IR-7, IR-8, IR-8B, and IR-9 centrifuges were being tested with natural uranium feed but not accumulating enriched uranium. As of May 2022, not a single IR-2, IR-3, IR-6M, IR-6sm, or IR-8s centrifuge was listed as present in any of the three enrichment plants. The IR-2 and IR-3 centrifuges may have been retired. An additional new centrifuge type, the IR9-1B, is discussed in Chapter 1 (see main report), but it has not been deployed at the PFEP to this date and is not included in Figure H.2. Figure H.3 shows the fraction of each type in a pie chart.

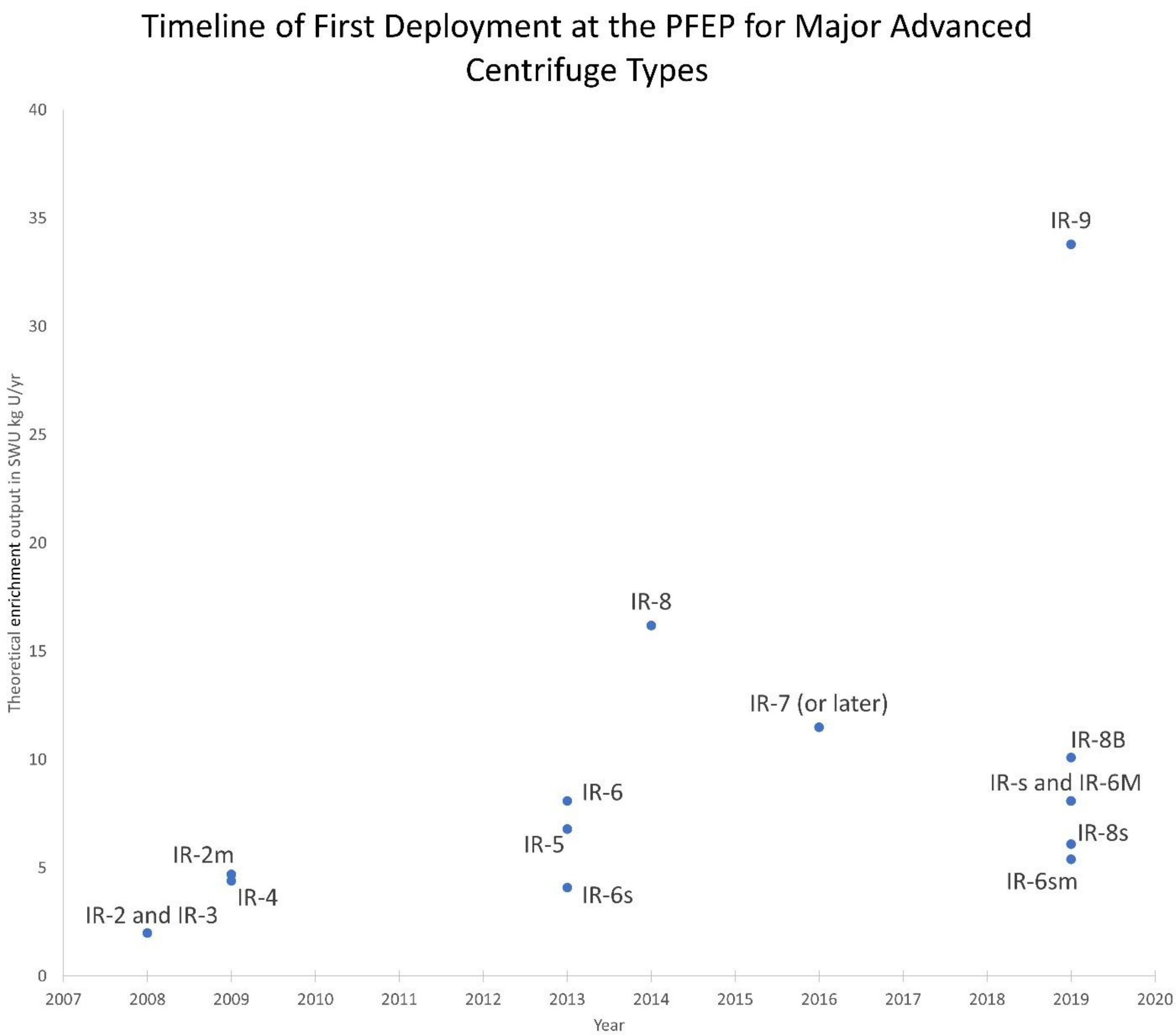


Figure H.2. Timeline of Iran's deployment of major advanced centrifuge types at the Natanz Pilot Fuel Enrichment Plant, in relation to their theoretical enrichment output, starting with the IR-2 and IR-3 in 2008. Where data exist, the theoretical output proved significantly greater than the practical values Iran achieved when the centrifuges enriched uranium either alone or in cascades.

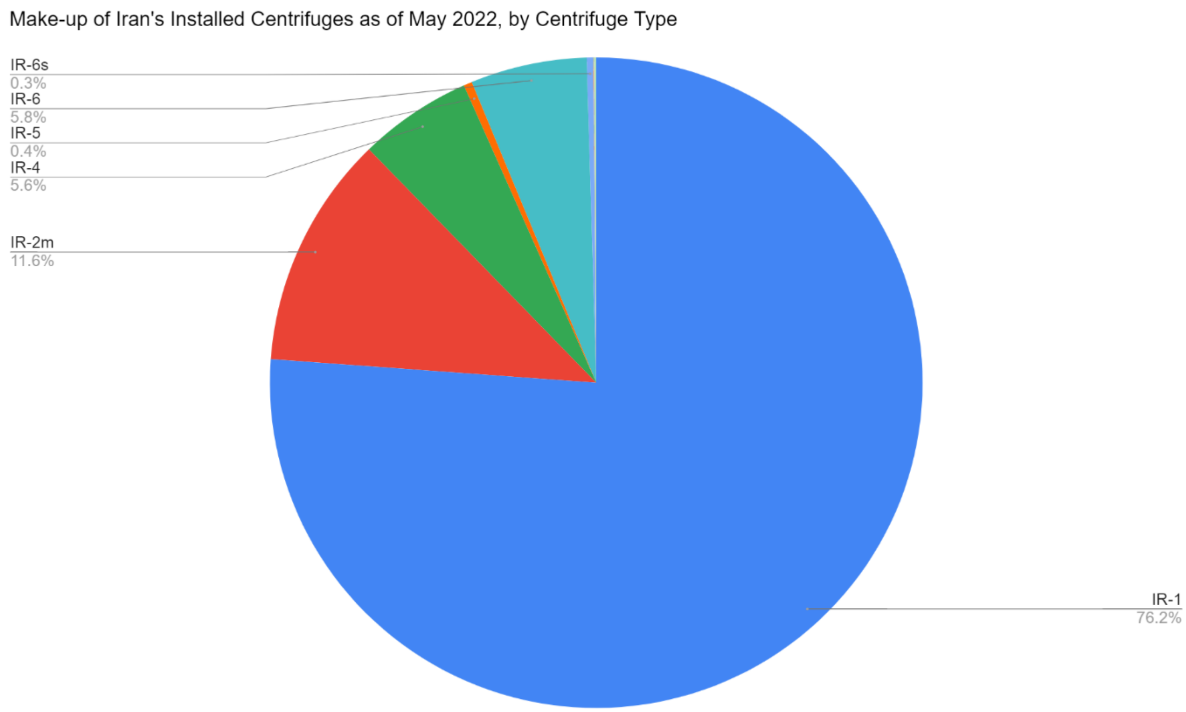


Figure H.3. The fraction by type and number of Iran's installed centrifuges at all facilities as of May 2022. The IR-7 (1 installed), IR-8 (1 installed), IR-8B (1 installed), IR-9 (1 installed), and IR-s (10 installed) centrifuge types are represented on this graph, however, the respective counts are too few to be seen.

The JCPOA reduced the number of installed IR-2m and IR-4 centrifuges temporarily, but despite limitations, it only reduced the number of IR-6 centrifuges for a relatively short period of time, and it did not slow Iran's ability to produce and deploy advanced centrifuges once Iran decided to stop abiding by the JCPOA limits (see Annex for their historical deployments). Iran has demonstrated its ability not only for a nuclear snap-back but also for a snap nuclear build-up.

In reviewing Iran's work on advanced centrifuges, the step from single machine tests to small cascade testing appears critical. However, under the JCPOA, this step was allowed from year one of the JCPOA's implementation for the IR-6 and IR-8 centrifuges, and not enforced sufficiently for the IR-6 centrifuge.

Iran has gained valuable technical knowhow, experience, and advancements in the designing and building of its advanced centrifuges, further enabling a rapid build-back or build-up of centrifuge capabilities. Those gains cannot be reversed or erased, presenting further challenges in seeking to reestablish JCPOA limits.

Enrichment Output of Advanced Centrifuges

Figure H.4 provides Iran's total historical theoretical enrichment capacity at Natanz and Fordow, where the IR-1 capacity is in blue and advanced centrifuge capacity is in red. So far, Iran’s current enrichment capacity has not exceeded its total capacity prior to the JCPOA’s implementation, but the nature of that capacity has shifted predominately to advanced centrifuges.

Because of their far greater enrichment outputs, the installed advanced centrifuges, although many fewer in number, began in May 2021 to exceed the enrichment capacity of the several thousands of installed IR-1 centrifuges. As of November 2021, the advanced centrifuges numbered about 2100, or about 34 percent of the number of deployed IR-1 centrifuges at Natanz and Fordow, and they out-produced the 6290 deployed IR-1 centrifuges in enrichment output by about 48 percent. As of May 2022, the advanced centrifuges numbered about 2228, or about 31 percent of the number of deployed IR-1 centrifuges at Natanz and Fordow, and they out-produced the 7110 deployed IR-1 centrifuges in enrichment output by about 41 percent, reflecting an increase in the number of IR-1 centrifuges installed since November 2021 (see Figure H.5 for a breakdown of the total installed enrichment capacity by centrifuge type).

If Iran reaches the projected number of 3400 advanced centrifuges, they will have almost two times the enrichment capacity of the currently deployed IR-1 centrifuges. This advanced centrifuge capacity will also rival all of Iran’s estimated 16,000 IR-1 centrifuges—deployed *and* stored—with only 21 percent of the number of centrifuges. This comparison ignores any stored advanced centrifuges.

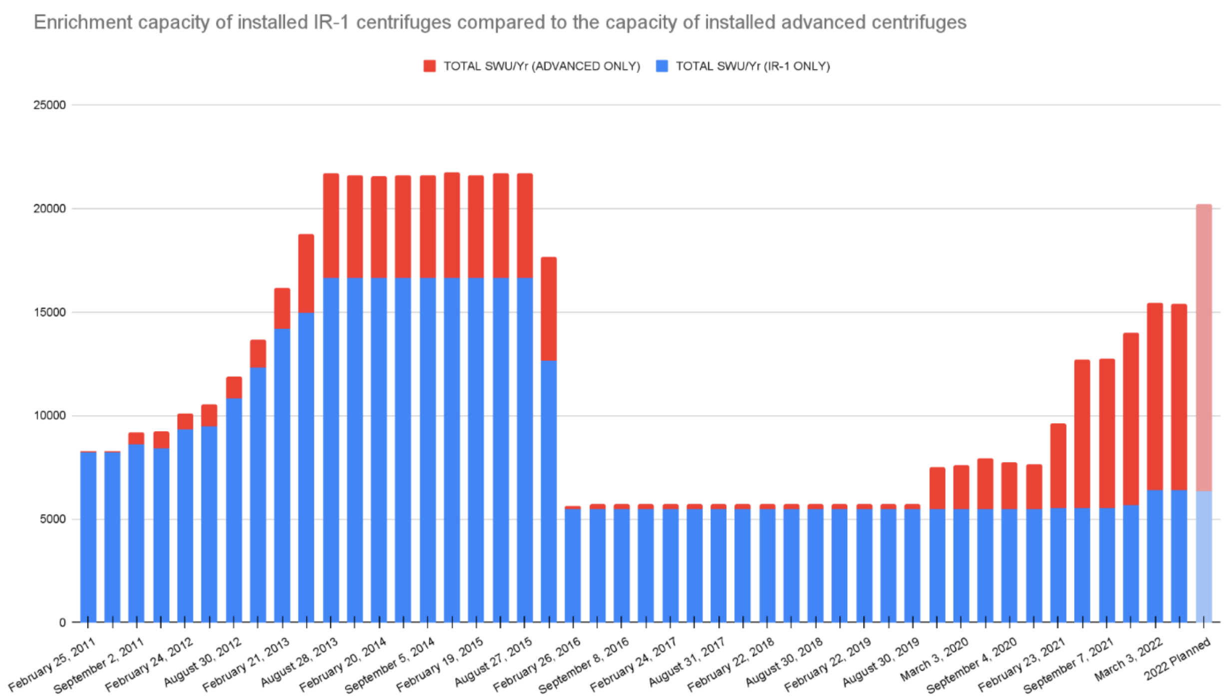


Figure H.4. Total enrichment capacity, by quarter, of the installed IR-1 and advanced centrifuges, with a projection on the far right of the graph.

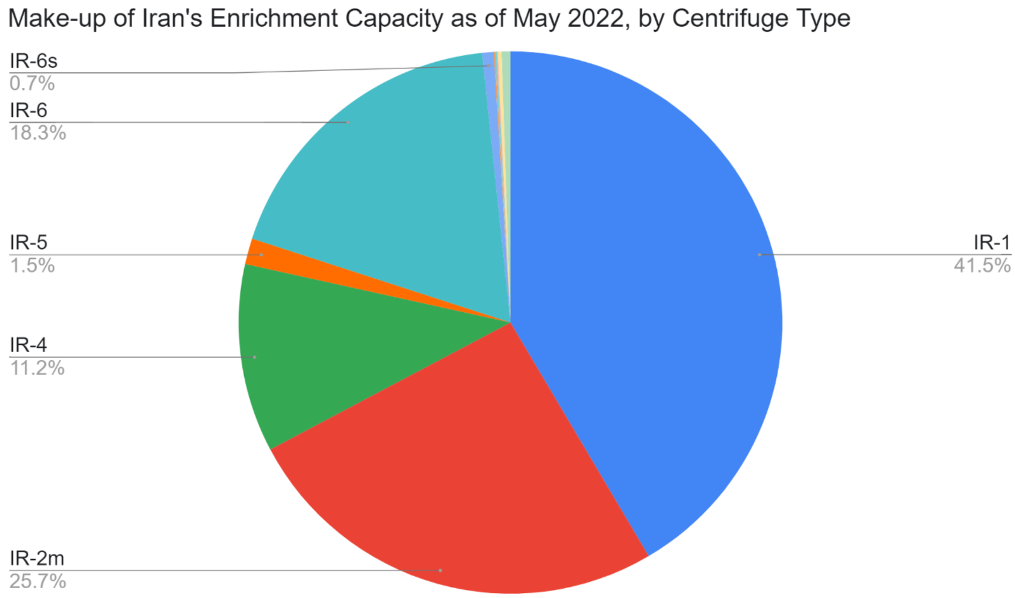


Figure H.5. The make-up of Iran's total installed enrichment capacity organized by centrifuge type. Despite the IR-1 accounting for 76 percent of the total installed centrifuges in terms of number (see Figure H.3), it only accounts for about 42 percent in terms of the installed enrichment capacity. The IR-2m, IR-4, and IR-6 make up about 55 percent, and the IR-5 and IR-6s about 2 percent of the installed capacity. The other installed advanced centrifuge types contribute only slightly to the total capacity and are not annotated in the pie chart.

Increasing Advanced Centrifuges' Enrichment Output

In its development of advanced centrifuges, Iran has lengthened its centrifuge rotor assemblies, boosted the rotor's wall speed marginally by increasing the diameter, and changed the rotor tube material to carbon fiber. Carbon fiber allows for higher rotor speeds than the high strength aluminum used in Iran's IR-1 centrifuge. Iran could have also achieved higher speeds by opting for high strength maraging steel rotor assemblies, as Pakistan did, but Iran appears to have encountered difficulties procuring this material. However, excluding the IR-1 centrifuge, Iran's enrichment output appears to have increased mostly with length, indicating Iran has had difficulties operating its centrifuges at the higher speeds offered by carbon fiber rotors.

Difficulties with high strength maraging steel appear to have also motivated Iran to develop the bellows, an important component of Iran's longer centrifuges, from carbon fiber, although carbon fiber bellows are much more difficult to make than ones made from maraging steel. Not unexpectedly, Iran appears to have ongoing difficulties making carbon fiber bellows, continuing to deploy shorter centrifuge models that do not need a bellows in parallel to developing the longer centrifuges. It is also concentrating on deploying advanced centrifuges with only one bellows, a centrifuge design easier to develop than one with two or more bellows. In addition, as mentioned above, Iran may be aiming to substitute maraging steel bellows for carbon fiber ones at least in the IR-6.

The IR-s centrifuge bears watching. It is an outlier among the shorter centrifuges, with a relatively high theoretical enrichment output, implying a wall speed more consistent with the potential of carbon fiber rotors. Typically, Iran's advanced centrifuges have achieved speeds less than optimal for carbon fiber rotors. However, the IR-s may be testing at these higher speeds, say of the order of 700 meters per second. Achieving these higher speeds is difficult but would allow significant increases in enrichment output.

In general, the AEOI has tried to develop many types of centrifuges, far too many for a commercial or economic program. Some of the developments, such as the proudly proclaimed very long centrifuges, appear aimed at impressing a domestic audience and not at large scale deployments in a reasonable time frame. Nonetheless, the strategic nature of Iran's centrifuge program cannot be ignored.

Growing Uncertainties about Advanced Centrifuge Production

As discussed above, recent attacks on the Natanz Iran Centrifuge Assembly Center and the centrifuge manufacturing plant at Karaj have likely limited, or slowed Iran's ability to install advanced centrifuges. Nonetheless, advanced centrifuge production rates are hard to predict, because of unclear Iranian policies on the number produced versus deployed, and less Iranian transparency at its centrifuge manufacturing sites since February 2021. In addition, the sabotage events at Natanz and Karaj have limited the production of centrifuges to an unknown extent. While the November 2021 IAEA report contained no information on the operational status of the Karaj site, the *Wall Street Journal* reported that the site resumed centrifuge production on a limited scale in August 2021 and accelerated production subsequently, producing "at least 170 advanced centrifuges" by mid-November.[8] Shortly after Iran allowed the IAEA to re-install cameras at Karaj in December 2021, Iran announced it was moving the centrifuge rotor and bellows production workshop to a new site at Esfahan, subsequently changed to the FEP at Natanz.[9] Based on IAEA reporting, centrifuge part manufacturing has commenced at Natanz; Iran informed the IAEA that production of centrifuge rotor tubes and bellows would begin on April 13, 2022.[10] A year prior, Iran inaugurated a small, temporary workshop that serves as a centrifuge assembly facility at Natanz

[8] Laurence Norman, "Iran Resumes Production of Advanced Nuclear-Program Parts, Diplomats Say," *The Wall Street Journal*, November 16, 2021, https://www.wsj.com/articles/iran-resumes-production-of-advanced-nuclear-program-parts-diplomats-say-11637079334.

[9] David Albright, Sarah Burkhard, and Andrea Stricker, "Analysis of IAEA Iran Verification and Monitoring Report - March 2022," *Institute for Science and International Security*, March 4, 2022, https://isis-online.org/isis-reports/detail/analysis-of-iaea-iran-verification-and-monitoring-report-march-2022; Francois Murphy, "Iran moves centrifuge-parts workshop underground at Natanz, IAEA says," Reuters, April 28, 2022, https://www.reuters.com/world/middle-east/iran-set-up-centrifuge-parts-workshop-underground-natanz-iaeasays-2022-04-28/; and IAEA Director General, Verification and Monitoring in the Islamic Republic of Iran in light of United Nations Security Council Resolution 2231 (2015), GOV/INF/2022/11, April 14, 2022.

[10] "Analysis of IAEA Iran Verification and Monitoring Report - May 2022."

Construction of a replacement for the ICAC in a new tunnel complex is progressing visibly.[11] The new tunnel complex will harbor halls more deeply buried than the Fordow uranium enrichment site, itself deeply buried, and features tunnel entrances that appear better protected as well. This site is expected to be large enough to produce centrifuges on the same scale as planned for the ICAC, namely several thousand advanced centrifuges per year. In fact, the estimated available floor space underneath the mountain ridge and between the visible tunnel entrances appears to significantly exceed that of the ICAC, leading to concerns that the site may have additional purposes, including housing a small enrichment facility containing advanced centrifuges.

Sneak Out in a Clandestine Plant

More powerful advanced centrifuges make it easier for Iran to set up a secret enrichment plant, which would be smaller and host only a fraction of the centrifuges Iran would have needed in 2009, when it was trying to finish up and install IR-1 centrifuges at its secret enrichment plant near Qom (now known as Fordow FEP), designed to produce weapon-grade uranium.[12] Using the Amad Plan as a guide, if a secret enrichment site had 1000 IR-6 centrifuges and used 4.5 percent enriched uranium as feedstock, it could produce significantly more weapon-grade uranium in a smaller space than the Fordow site outfitted with its planned 3000 IR-1 centrifuges.

Since only a relatively small number of advanced centrifuges would be needed to set up a secret and relatively powerful enrichment plant, concern increases about unaccounted production of major parts for advanced centrifuges or whole rotor assemblies.

The concern about Iran building another secret enrichment plant will undoubtedly grow with time, absent negotiated limits and far more robust IAEA inspections than have functioned in Iran with or without the JCPOA. After all, the Natanz enrichment plant and the Fordow enrichment plant were built in secret until exposed, the latter as part of a covert military program to produce weapon-grade uranium, a facility that went undiscovered for upwards of six or seven years.[13] With advanced centrifuges, a secret plant could be smaller, more capable, and harder to discover, and this possibility should not be discounted.

---

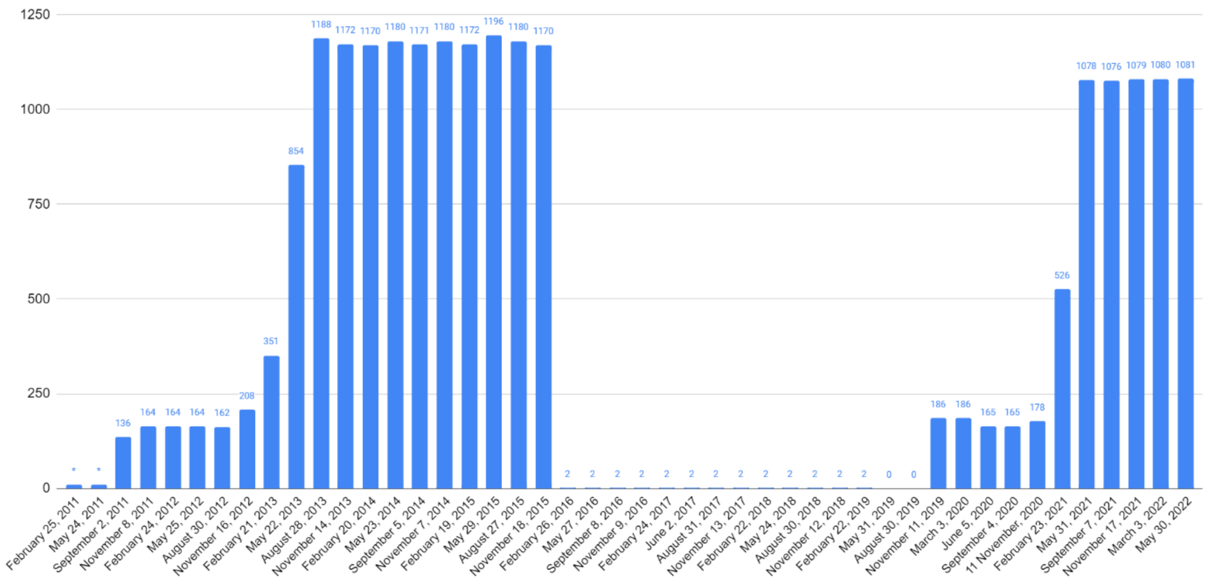
[11] David Albright, Sarah Burkhard, and John Hannah, "Iran's Natanz Tunnel Complex: Deeper, Larger than Expected," *Institute for Science and International Security,* January 13, 2022, https://isis-online.org/isis-reports/detail/irans-natanz-tunnel-complex-deeper-larger-than-expected; and "Imagery Update: Iran Continues to Harden its New Natanz Tunnel Complex."

[12] David Albright with Sarah Burkhard and the Good ISIS Team, *Iran's Perilous Pursuit of Nuclear Weapons,* (Washington, DC: Institute for Science and International Security, 2021).

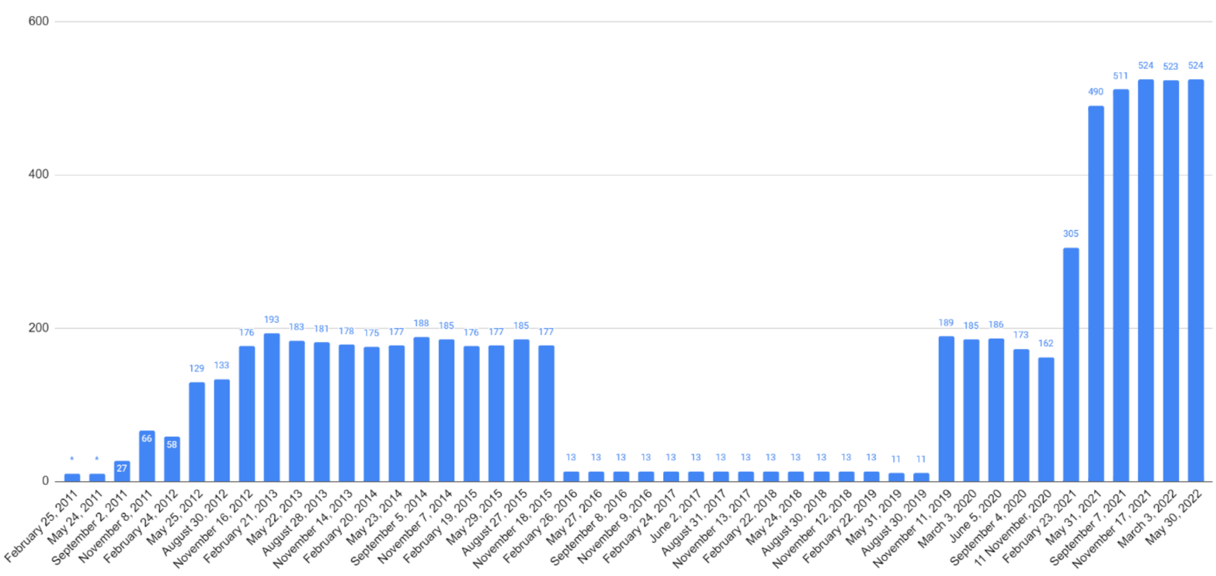
[13] *Iran's Perilous Pursuit of Nuclear Weapons.*

Annex. Numbers of IR-2m, 4, and 6 Centrifuges, historical deployments, by quarter

IR-2m deployment at PFEP and FEP from 2011 - 2022



IR-4 deployment at PFEP and FEP from 2011 - 2022



IR-6 deployment at the PFEP and FFEP from 2013 - 2022