INSTITUTE FOR SCIENCE AND INTERNATIONAL SECURITY

REPORT

Analysis of IAEA Iran Verification and Monitoring Report - November 2021

By David Albright, Sarah Burkhard, and Andrea Stricker[1]

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This report summarizes and assesses information in the International Atomic Energy Agency's (IAEA) quarterly safeguards report for November 17, 2021, *Verification and monitoring in the Islamic Republic of Iran in light of United Nations Security Council resolution 2231 (2015)*, including Iran's compliance with the Joint Comprehensive Plan of Action (JCPOA).

The IAEA's latest report details Iran's rapidly advancing nuclear activities and steps to limit IAEA monitoring, indicating the inspectors' diminished ability to detect Iranian diversion of assets to undeclared facilities. At the same time, the IAEA has made no progress on resolving outstanding safeguards issues relating to the presence of undeclared nuclear material and activities in Iran. The latter is discussed in a separate quarterly IAEA safeguards report, *NPT (Nuclear Non-Proliferation Treaty) Safeguards Agreement with the Islamic Republic of Iran*, issued also on November 17 and analyzed separately by the Institute.[2] In these reports, and during IAEA Director General Rafael Grossi's public appearances, the IAEA Secretariat has sounded an alarm to the Board of Governors and to the international community.

Highlights and Breakout Estimate

- Iran has enough enriched uranium hexafluoride (UF_6) in the form of near 20 and 60 percent enriched uranium to produce enough weapon-grade uranium (WGU), taken here as 25 kilograms (kg), for a single nuclear weapon in as little as three weeks. It could do so without using any of its stock of uranium enriched up to 5 percent as feedstock. The growth of Iran's stocks of near 20 and 60 percent enriched uranium has dangerously reduced breakout timelines.
- Iran could continue producing more weapon-grade uranium, using its substantial stock of uranium enriched between two and five percent. In just over two months after the commencement of breakout, Iran could have produced enough additional WGU for a second weapon. After about 3.5 months, it would have enough for a third weapon. The

[1] Andrea Stricker is a research fellow at the Foundation for Defense of Democracies (FDD).

[2] David Albright, Sarah Burkhard, and Andrea Stricker, "The IAEA's Iran NPT Safeguards Report - November 2021," *Institute for Science and International Security*, November 17, 2021, https://isis-online.org/isis-reports/detail/the-iaeas-iran-npt-safeguards-report-november-2021.

additional production of enough WGU for a fourth weapon would be slower, taking six months, reflecting the depletion of Iran's pre-existing stocks of enriched uranium.

- Iran appears to have continued producing near 20 percent enriched uranium metal, although the IAEA does not provide details in its latest report. Despite Iran's claims of civil use, uranium metal is a key material in nuclear weapons. Iran's move to create the wherewithal to make uranium metal as well as making the metal itself is concerning because Iran is both instituting a nuclear weapons capability and increasing its knowledge and experience in this key area.
- Iran experimented with using near 20 percent enriched uranium as feed in advanced centrifuges at the Natanz Pilot Fuel Enrichment Plant (PFEP), likely gaining important new knowledge in producing highly enriched uranium (HEU) using advanced centrifuges. This is also the first time Iran has started feeding a centrifuge cascade with uranium enriched more than 5 percent at any of its three enrichment plants, possibly gaining additional, irreversible knowledge in setting up and using equipment designed for smaller feed quantities and higher enriched uranium feed.
- In essence, Iran is effectively breaking out slowly by producing 60 percent enriched uranium and continuing to accumulate it. As of November 6, Iran had a stock of 17.7 kg of near 60 percent enriched uranium (in uranium mass or U mass), or 26.1 kg (in hexafluoride mass). If Iran accumulated about 40 kg of 60 percent enriched uranium (U mass), it would have enough to be able to further enrich it and quickly produce 25 kg of weapon-grade uranium (U mass) in just a few advanced centrifuge cascades.
- Alternatively, 40 kg of 60 percent enriched uranium is more than enough to fashion a nuclear explosive directly, without any further enrichment, although Iran's known nuclear weapons designs use WGU.
- Iran's current production rate of 60 percent enriched uranium is 42 kg per year (U mass), meaning that it could accumulate its first amount of 40 kg in about 6.4 months, or by the spring of 2022.
- Iran is learning important lessons in producing WGU and breaking out to nuclear weapons by experimenting with skipping typical enrichment steps as it enriches up to 60 percent uranium-235. It is starting from a level below 5 percent LEU and enriching directly to near 60 percent in one cascade, rather than using two steps in between, a slower process entailing the intermediate production of 20 percent enriched uranium. Iran is also implementing a plan to allow IR-6 cascades to switch more easily from the production of 5 percent enriched uranium to 20 percent enriched uranium. As such, Iran is experimenting with multi-step enrichment while seeking to shortcut the process.
- Iran is also improving its ability to recycle tails from its 60 percent enriched uranium production, recovering about 50 percent of the needed 5 percent LEU feed and producing tails closer to 2 percent enriched uranium.
- The production rate of 20 percent enriched uranium at the Fordow Fuel Enrichment Plant (FFEP) and PFEP remained constant for this reporting period, at a monthly average of 13.2 kg (U mass), or 19.5 kg (hex mass).
- As of November 6, 2021, Iran had an IAEA-estimated stock of 113.8 kg of 20 percent enriched uranium (U mass and in the form of UF_6), an increase from the previous reporting

period's 84.3 kg of 20 percent enriched uranium in UF_6 form. Iran also has an additional stock of 34.2 kg (U mass) of 20 percent uranium in other chemical forms.

- In a new development, as of November 9, 2021, Iran installed 166 IR-6 centrifuges in a cascade at the FFEP. It also has a total of 23 IR-6 centrifuges in a second cascade. At the end of the last reporting period, only ten IR-6 centrifuges had been installed in this second cascade. The installation of advanced centrifuges at the FFEP enhances Iran's ability to break out using a declared but highly fortified facility.
- Using uranium metal, Iran made 20 percent uranium silicide and two fuel plates using the new silicide fuel for the Tehran Research Reactor (TRR). The fuel has yet to undergo quality control, but Iran's production of this type of fuel plate is unnecessary and a major violation of the JCPOA. It is likely a pretext to add to its nuclear weapons capabilities.
- The number of enriching IR-1 cascades and IR-2m cascades at the Natanz Fuel Enrichment Plant (FEP) appears to have almost fully recovered from a sabotage incident in April. Iran has installed 31 cascades of IR-1 centrifuges, six cascades of IR-2m centrifuges, and two cascades of IR-4 centrifuges at the FEP. Of those, as of November 13, 28 IR-1 cascades, six IR-2m cascades, and two IR-4 cascades "were being fed" with uranium.
- Iran's current operating enrichment capability is estimated to be about 12,400 separative work units (SWU) per year, compared to 11,700 SWU per year at the end of the last reporting period.
- Iran's total usable stock of below 5 percent LEU decreased just slightly compared to the previous reporting period. This stock did not change much because its increased use as feed to produce 60 percent enriched uranium at the PFEP was offset by a simultaneous increase in production at the PFEP.
- Near 5 percent LEU production during this reporting period, which spanned 69 days at the Natanz FEP, totaled 339 kg (U mass), with a daily average production rate of 4.9 kg (U mass), a slight decrease from the previous reporting period's daily average production rate of 5.26 kg (U mass). This reflects Iran's slightly increased enrichment capacity at the FEP, combined with its reverting to natural uranium feed rather than 2 percent LEU feed, which Iran had used intermittently during the previous reporting period.
- The IAEA report does not discuss the status of Iran's construction of a new advanced centrifuge assembly facility in a tunnel near the main Natanz complex.
- As noted in a separate IAEA report,[3] and independent of problems caused by Iran's suspension of the AP and JCPOA monitoring, Iran has failed to cooperate with the IAEA regarding the agency's finding of uranium particles at three undeclared sites and answer questions about a fourth site, leading Director General Grossi to state, "The lack of progress in clarifying the Agency's questions concerning the correctness and completeness of Iran's safeguards declarations seriously affects the ability of the Agency to provide assurance of the peaceful nature of Iran's nuclear program."
- Iran has not turned over to the IAEA a missing recording unit and storage data from a camera that was destroyed at the TESA (or TABA) centrifuge manufacturing facility near

[3] "The IAEA's Iran NPT Safeguards Report - September 2021"; and David Albright, Sarah Burkhard, and Andrea Stricker, "The IAEA's Latest Iran NPT Safeguards Report: No Progress, No Accountability?" *Institute for Science and International Security*, June 4, 2021, https://isis-online.org/isis-reports/detail/the-iaeas-latest-iran-npt-safeguards-report-no-progress-no-accountability.

Karaj, the site of a sabotage event in June.[4] Iran has also not permitted the IAEA to re-install cameras at the site, reneging on a September 2021 agreement with the IAEA to permit the IAEA to service measurement devices and video cameras at the Karaj site and other nuclear sites. The IAEA states the agreement did not exclude the Karaj facility.

- Around five months have passed since the IAEA has had video monitoring at the TESA facility, raising concern that the IAEA cannot restore continuity of knowledge of events at the site. The IAEA has not had insight into how many advanced centrifuges Iran has made at the site since February, and therefore no awareness of whether Iran has diverted advanced centrifuges to a secret storage site, or for that matter, a clandestine enrichment plant.
- Even if Iran continues to permit the IAEA to service agency equipment, the verification process may now face such serious gaps that it is impossible to restore the IAEA's continuity of knowledge of Iran's nuclear activities, which is so vital to verification.
- Combined with outstanding safeguards issues in Iran, the IAEA has a significantly reduced ability to monitor Iran's complex and growing nuclear program, which notably has unresolved nuclear weapons dimensions. The IAEA's ability to detect diversion of nuclear materials, equipment, and other capabilities to undeclared facilities has greatly diminished.

Part 1: Enriched Uranium Stocks

At the Natanz FEP, Iran produced approximately 501.4 kg of UF_6 enriched up to 5 percent U-235 during the reporting period, which spanned 69 days from August 28, 2021 to November 5, 2021. The report discusses this amount as kilograms of UF_6 in units of UF_6 mass, which the authors refer to as hex mass. The total uranium mass would be 339 kilograms, for a monthly average production rate of 147 kg U mass and a daily production rate of 4.9 kg U mass, slightly below the last reporting period's average production rates, which were 158 kg U mass per month, and 5.26 kg U mass per day.[5]

Unlike during the last reporting period, where Iran used 2090.0 kg hex mass (1412.8 kg U mass) of its near 2 percent LEU stock as feed for the FEP, this report specifies that Iran used natural uranium as feed for the FEP.

At the FFEP, from August 30, 2021 to November 5, 2021, Iran produced 43.7 kg of UF_6 (hex mass) enriched up to 20 percent enriched uranium, or 29.5 kg U mass. It produced 262.6 kg of UF_6 hex mass (or 177.5 U mass) of up to 2 percent enriched uranium in tails. The daily average production

[4] "Iran Claims it Thwarted a 'Sabotage Attack' on Nuclear Facility," *CBS News/Associated Press*, June 23, 2021. https://www.cbsnews.com/news/iran-claims-sabotage-attack-on-nuclear-facility-karaj/

[5] The fact that the production values are reported in uranium hexafluoride mass can only be verified by comparing the production values to the differences in stockpile from one reporting period to the next. The differences in stockpile are consistently two-thirds of the given produced quantity, showing that the former is in uranium mass and the latter in uranium hexafluoride mass. Adding to the confusion is that this practice is maintained in the report's table in Annex III of the IAEA report; although the table at the top indicates quantities given in kgU, the values appear to be in uranium hexafluoride mass. The quantities given in kg U in the bottom table appear to be in uranium mass.

rate of 20 percent enriched uranium at the FFEP has remained near constant during the last six months, at 0.65 kg (hex mass) or 0.44 kg (U mass). At this rate, Iran could produce 19.6 kg of near 20 percent enriched uranium per month (hex mass) or 13.2 kg (U mass). Annually, Iran could produce 237 kg (hex mass) or 160.6 kg (U mass).

At the PFEP, Iran produced 2 percent enriched uranium, up to 5 percent enriched uranium, and up to 60 percent enriched uranium stock during the reporting period. It did not produce any 20 percent enriched uranium at the PFEP, unlike during the last reporting period; instead, it produced greater quantities of 60 percent enriched uranium. Between August 30, 2021 and November 5, 2021, the PFEP produced 11.4 kg hex mass of near 60 percent enriched uranium (equivalent to 7.7 kg U mass); 294.5 kg hex mass of up to 5 percent LEU (199 kg U mass); and 360.7 kg hex mass of uranium enriched to up to 2 percent U-235 (244 kg U mass).

The 60 percent enriched uranium production rate during this reporting period was 7.7 kg (U mass) over 67 days, resulting in a daily average production rate of 0.115 kg (U mass) or a monthly average production rate of 3.5 kg (U mass), or 5.18 kg (hex mass). This rate is up from the previous reporting period's monthly average production rate of 2.4 kg, reflecting an increase of about 50 percent. Annually, Iran could produce 42 kg of 60 percent enriched uranium (U mass).

Of the 2 percent LEU, Iran produced 104.2 kg hex mass (70 kg U mass) in PFEP lines 2, 3, and 5 and 256.5 kilograms hex mass (173 kg U mass) enriched up to 2 percent as tails in line 1.

Due to the reduced monitoring measures, the IAEA can only verify the amount of LEU removed from the process as a product and not the amount that is still in process, but it is able to reliably estimate total amounts.

Estimates of additional amounts of LEU in oxides and intermediate products, fuel assemblies and rods, and in scrap, add up to 176.3 kg U mass, more than twice the amount of the previous reporting period, and more than four times greater than during the reporting period before that. This increase applies mostly to the uranium oxide and intermediate estimate (90.9 kg increase) and the uranium in fuel assemblies and rods (14.3 kg increase). The report specifies that out of the 176.3 kg enriched to unspecified levels (U mass), 103.4 kg are up to 5 percent LEU and 34.2 kg are up to 20 percent LEU.

Of its near 5 percent LEU stock, Iran fed 310.8 kg hex mass (or 210 kg U mass) into the tandem cascades at Fordow, maintaining an average feed rate of about 4.6 kg per day hex mass, or 3 kg U mass. It dumped 4.5 kg near 5 percent LEU feed (hex mass), or about 3 kg in uranium mass, representing 1.4 percent of the total feed. During the previous reporting period, it dumped 34.3 kg (hex mass) of near 5 percent LEU, out of a total feed of 444.3 kg (hex mass), representing 7.7 percent. It also fed 562.3 kg of near 5 percent hex mass (380 kg U mass) into PFEP R&D lines 1, 4, and 6, more than during the previous reporting period, despite the previous period covering a longer time span. During the previous reporting period, Iran fed a daily average of 4.3 kg (hex mass) or 2.9 kg U mass per day; during the most recent period, this almost doubled to 8.1 (hex mass) and 5.4 kg (U mass). The increase in feed reflects the current 60 percent enriched uranium

production in line 6 *and* line 4, where during most of the previous reporting period, line 4 was instead used to produce 20 percent enriched uranium.

Based on this information, Iran's new stockpile of near 5 percent LEU in uranium mass should be the sum of 1774.8 kg U mass from the last reporting period, 339 kg from the FEP, and 199 kg from the PFEP, with the feed of 590 kg subtracted, resulting in 1722.8 kg. Subtracting the 103.4 kg not in the form of UF_6 and adding the 3 kg (U mass) dumped in the FFEP, this total becomes 1622.4 kg, almost matching the 1622.3 kg U mass of near 5 percent LEU in UF_6 form that the IAEA reported.

Of its near 20 percent enriched uranium stock, Iran fed an unspecified amount into a variety of advanced centrifuges at the PFEP. Since Iran was not accumulating enriched uranium, and was instead combining the product and tails, the levels of enriched uranium achieved are not included in the report and may also not be known to the IAEA.

The net overall enriched uranium stock, including all levels of enrichment and all chemical forms, increased slightly by 49 kg from 2441 kg U mass to 2490 kg (see Table 1), a significant change from the previous reporting period, where it decreased by 800 kg. The near 5 percent LEU stock in the form of UF_6 decreased by 152.5 kg (U mass), but, taking into account the 103.4 kg in different chemical forms, the overall near 5 percent LEU stockpile decreased only by 49.1 kg (U mass). Unlike during the last reporting period, where Iran's near 2 percent LEU stock decreased by 864 kg, Iran was able to maintain the stock during this reporting period and even increase it by 55.8 kg to 559.6 kg (U mass). The near 20 percent enriched uranium stock increased by 29.5, from 84.3 kg to 113.8 kg (U mass), and the near 60 percent enriched uranium stock increased by 7.7 kg to 17.7 kg (U mass). The remaining discrepancy in the overall enriched uranium stock increase is due to an increase in uranium in other chemical forms.

Starting in April 2021, Iran was using a combination of R&D lines 1, 4, and 6 to feed 5 percent LEU into line 6 to produce 60 percent enriched uranium, feed the tails into line 4 to produce 20 percent enriched uranium, and feed those tails in line 1 to produce 5 percent LEU. In April, of the 57.7 kg (hex mass) fed into the process, Iran turned 1.6 kg (2.8 percent) into 60 percent enriched uranium, 2.4 kg (4.2 percent) into 20 percent enriched uranium, 9 kg (15.6 percent) into 5 percent LEU, and 44.7 kg (77.5 percent) remained as tails enriched slightly above natural uranium. During the reporting period spanning May to August 2021, of the 427.2 kg (hex mass) that were fed into the process, Iran turned 11.3 kg (2.6 percent) into 60 percent enriched uranium, 19.2 kg (4.5 percent) into 20 percent enriched uranium, 92.6 kg (21.7 percent) into 5 percent LEU, and 307.1 kg (71.9 percent) remained as tails enriched to about 1 percent U-235. During this most recent reporting period, spanning August 30, 2021 to November 5, 2021, Iran was feeding 5 percent LEU into both line 4 and line 6 to produce 60 percent HEU, and it fed those tails in line 1 to produce 5 percent LEU. Of the 562.3 kg (hex mass) of 5 percent LEU fed into lines 4 and 6, Iran turned 11.4 kg (2 percent) into 60 percent enriched uranium, 294.5 kg back into 5 percent enriched uranium (52 percent), and 256.5 kg (46 percent) remained as tails enriched up to 2 percent. While the product to feed ratio suffered slightly for the 60 percent production, Iran continued to improve its ability to recycle its tails, recovering 52 percent of the 5 percent feed, up from 21.7 percent during the previous reporting period, and minimizing its tails enriched to below 2 percent.

Table 1. Enriched Uranium Quantities,* including less than 5 %, up to 20 %, and up to 60 % enriched uranium (all quantities in uranium mass)

Chemical Form	November 2, 2020	February 16, 2021	May 22, 2021	August 30, 2021	November 6, 2021
UF_6 (kg)	2408.5	2933.1	3206.3	2372.9	2313.4
Uranium oxides and their intermediate products (kg)	15.5	13.3	13.3	34.5	125.4
Uranium in fuel assemblies and rods (kg)	8.2	10.5	10.5	21.1	35.4
Uranium in liquid and solid scrap (kg)	10.7	10.9	10.9	12.8	15.5
Enrichment Level Subtotals					
Uranium enriched to 3.67 percent (kg)	215.1	-	-	-	-
Uranium enriched up to 5 percent (kg) but more than 2 percent and in the form of UF_6	1535.1	1890	1773.2	1774.8	1622.3
Uranium enriched up to 2 percent (kg)	692.7	1025.5	1367.9	503.8	559.6
Uranium enriched up to 20 percent (kg) and in the form of UF_6	0	17.6	62.8	84.3	113.8
Uranium enriched up to 60 percent (kg)			2.4	10	17.7
Uranium in chemical forms other than UF_6 with unspecified enrichment level (kg) (including 103.4 kg up to 5 % LEU and 34.2 kg up to 20 % LEU)		34.7	34.7	68.4	176.3
Totals of Enriched Uranium in UF_6, <5 % (kg)		2915.5	3141.1	2278.6	2181.9
Totals of Enriched Uranium in UF_6, including near 20 % and near 60 % (kg)		2933.1	3206.3	2372.9	2313.4
Totals of Enriched Uranium in all chemical forms, <5 % <20 % and <60 % enriched	**2442.9**	**2967.8**	**3241**	**2441.3**	**2489.7**

*These totals do not include undisclosed stocks of enriched uranium exempted by the JCPOA Joint Commission.

Part 2: Enrichment capacity

Natanz Fuel Enrichment Plant

As of November 12, 2021, in total, 31 cascades of IR-1 centrifuges, six cascades of IR-2m centrifuges, and two cascades of IR-4 centrifuges were installed to enrich natural UF_6 up to 5 percent. At that time, 28 IR-1 cascades (down from 29 cascades at the end of the previous reporting period), six IR-2m cascades (up from five cascades), and two IR-4 cascades (same amount) were being fed with natural UF_6. Compared to two reports ago, when many of these cascades were not operating, Iran appears to have recovered from the April 11 sabotage event.

Overall, this suggests that Iran had sufficient stocks of IR-1 and IR-2m centrifuges to replace the destroyed ones, an amount comprising at least half of those installed on the day of the explosion.

While one new IR-1 cascade was installed during this reporting period, the IAEA also reported that Iran had not started installing a number of additional planned cascades: four IR-4 cascades, one IR-6 cascade, and five IR-1 cascades.

The quantity of IR-1 centrifuges Iran withdrew from JCPOA-mandated storage is not available for this reporting period because of Iran's refusal since February to provide the IAEA with access to the data and recordings collected by its equipment. This quantity would provide concrete evidence of the total number of centrifuges destroyed in the April incident.

Fordow Fuel Enrichment Plant

In a new development, as of November 9, 2021, Iran installed 166 IR-6 centrifuges in a cascade. It also added 13 IR-6 centrifuges to a second cascade, where at the end of the last reporting period, only ten IR-6 centrifuges had been installed. This second cascade had been fully modified to allow more flexible operation (see below).

Since January 2021, Iran has been using three sets of two interconnected IR-1 cascades to produce 20 percent enriched uranium from up to 5 percent LEU.

Earlier this year, Iran announced that it would install two IR-6 cascades to produce five percent feed for the tandem IR-1 cascades. On July 27, 2021, however, Iran informed the IAEA that it intended to make "some modifications on the configuration" of the two IR-6 cascades. The new configuration of the two IR-6 cascades will either be fed with natural UF_6 to produce UF_6 enriched up to 5 percent U-235 or with UF_6 enriched up to 5 percent U-235 to produce UF_6 enriched up to 20% U-235. The modification to the sub-headers of the two IR-6 cascades will enable Iran to "change the configuration of the cascades more easily." The modifications were completed on the "second cascade" (see above) by October 12, 2021. Iran also informed the IAEA at that time that the first cascade would not be modified, remaining in its original, fixed configuration.

Pilot Fuel Enrichment Plant

Iran continues planning the transfer of its enrichment research and development activities to a segregated area of Building A1000 at the FEP. Iran earlier completed the installation of sub-headers for 18 cascades in this new area, an increase of three-fold from the six lines in the above ground PFEP. On November 8, 2021, the IAEA verified that Iran had made "very limited progress" in the installation of infrastructure for these 18 cascades since August. The report does not provide a start date for this new area. Given its three-fold greater size, one must ask if this area could be devoted to production-scale enrichment in case of a surge in enriched uranium production or a breakout.

60 Percent Enriched Uranium Production in Lines 1, 4, and 6. Iran continued to use lines 1, 4, and 6 for the production of 60 percent enriched uranium and re-enrichment of tails, principally in a variety of cascade arrangements of IR-4 and IR-6 centrifuges. Since 60 percent production started on April 17, 2021, Iran has changed the mode of production several times, several of which were described in previous IAEA reports.

On November 8, 2021, the IAEA verified that Iran was continuing to feed up to 5 percent LEU into the two cascades in lines 4 and 6, comprising up to 164 IR-4 (potentially indicating an increase from 153 in the previous reporting period) and up to 164 IR-6 centrifuges, respectively, producing up to 60 percent enriched uranium. The tails from these two cascades were fed into the cascade of IR-5 and IR-6s centrifuges in line 1 to produce up to 5 percent enriched uranium. The assay of the tails is likely about 2-3 percent.

The IR-4 cascade in line 4 has an estimated enrichment output of about 607 separative work units per year (SWU/year). The IR-6 cascade in line 6 has a total estimated enrichment output of about 870 SWU/year. The two lines together have an estimated output of 1477 SWU/year, or the equivalent of about 1768 IR-1 centrifuges.

Lines 2 and 3. Iran implemented a new mode of operation in line 2, announced to the IAEA as feeding either 5 or near 20 percent enriched uranium into single advanced centrifuges, intermediate cascades of 10 advanced centrifuges, and intermediate cascades of 20 advanced centrifuges. During this reporting period, only near 20 percent enriched uranium was used as feed. Although the product and tails streams were re-combined, with no product collected, the experience gained in this procedure was likely important, particularly in the production of HEU in key advanced centrifuges when using near 20 percent enriched uranium feedstock. In fact, this is the first time Iran started feeding a cascade with uranium enriched higher than 5 percent at any of its enrichment plants, possibly gaining irreversible knowledge in the set up and use of feed equipment designed for smaller quantities and higher enriched uranium levels.

Between October 25 and November 8, 2021, Iran fed up to 20 percent enriched uranium into one single IR-6 centrifuge, one cascade of up to ten IR-6 centrifuges, and one single IR-4 centrifuge in line 2. On November 8, 2021, Iran was feeding up to 20 percent enriched uranium into a single IR-4 centrifuge and a cascade of seven IR-6 centrifuges; the other single centrifuges and the small and

intermediate cascades in line 2 were not being fed with UF_6. Notably, on November 16, 2021, Iran indicated that accumulating higher enriched uranium was not the goal of this exercise, stating that it had "'finished'" and that it would "'remove the temporary feeding set up'" and "return to the 'former process conditions.'" It is unclear what knowledge Iran gained, the enrichment levels it achieved, and the additional expertise it mastered.

Until October 23, and the switch in operation, line 2 accumulated up to 2 percent enriched uranium via natural uranium feed. Line 3 accumulated up to 2 percent enriched uranium throughout the reporting period. On November 8, 2021, for this purpose, Iran had been using single cascades of up to: nine IR-4 centrifuges; five IR-5 centrifuges; five IR-6 centrifuges, two cascades each of ten IR-6 centrifuges; 19 IR-6 centrifuges; and ten IR-s centrifuges.

The following single centrifuges were being tested with natural uranium but not accumulating enriched uranium: two IR-2m centrifuges, one IR-4 centrifuge; two IR-5 centrifuges; one IR-6 centrifuge; two IR-6s centrifuges; one IR-7 centrifuge; one IR-8 centrifuge; one IR-8B centrifuge; and one IR-9 centrifuge.

Line 5. Iran was feeding natural uranium into an intermediate cascade of 18 IR-1 centrifuges and an intermediate cascade of 33 IR-2m centrifuges (up from 32) in line 5 to produce uranium enriched up to 2 percent U-235.

Capacity of Centrifuges Enriching Uranium

Table 2 lists the estimated enrichment capacity by facility for those centrifuges enriching, leading to a total of 12,414 SWU/year, or the equivalent of 13,794 IR-1 centrifuges. This total number is slightly higher from the previous reporting period's 11,694 SWU/year, as Iran continues to restore its enrichment capability after an April 2021 explosion at the Natanz FEP. It is assumed that only those cascades inspectors observed to be enriching on November 13, 2021 are operational at Natanz, instead of all the installed cascades, which would include three additional IR-1 cascades. Iran also used additional advanced centrifuges in lines 2 and 3 at the PFEP this reporting period, increasing by about 40 the total number of centrifuges enriching and accumulating enriched uranium at the PFEP. There may be an additional 18 IR-6 and 2 IR-4 centrifuges that were fed with 20 percent enriched uranium between October 25 and November 8, 2021, which are not included in the PFEP count below. Iran also installed a full or near-full cascade of IR-6 centrifuges at the FFEP, which is not yet enriching and not included in the table below. Further, centrifuge numbers for line 1 are taken from the previous report, as they are not specified in this recent report. It must also be noted that the total enrichment capacity should not be used in breakout calculations, as many of the advanced centrifuges in the PFEP likely could not contribute meaningfully to the quick production of enough WGU for a nuclear explosive, starting with up to five percent or near 20 percent enriched uranium. However, see below for the case of 60 percent enriched uranium feed. Detailed breakout scenarios and timelines are discussed below.

Table 2. Quantity of enriching centrifuges and enrichment capacity

	Quantity of centrifuges	Enrichment capacity in SWU/yr	IR-1 equivalent
Natanz	6101	9389	10432
Fordow	1044	940	1044
Natanz PFEP*	526	2086	2318
Lines 2 & 3	See text		
Lines 1, 4, 5, 6	See text		
Total enriching	**7671**	**12414**	**13794**

*The values for lines 1, 2, 3, and 5 of the PFEP are rough estimates based on the use of estimated and measured values for the separative output of these centrifuges in cascades, as drawn from IAEA and Iranian information.

Practicing Breakout by Producing Highly Enriched Uranium

During this reporting period, Iran continued to produce 60 percent enriched uranium, or HEU. This level of enrichment is associated with a key step in the traditional stepwise process of climbing from natural uranium to 90 percent enriched uranium, or WGU. Iran also instituted the production of HEU, albeit on a limited scale, by feeding 20 percent enriched uranium into a small number of IR-4 and IR-6 centrifuges.

Sixty percent enriched uranium can be used directly in nuclear weapons. About 40 kg (U mass) is more than enough to make a nuclear explosive, compared to the less than 25 kg (U mass) of 90 percent enriched uranium the Institute uses as sufficient for Iran to manufacture a nuclear explosive. Iran's accumulation of 60 percent enriched uranium remains a highly provocative, dangerous step.

Moreover, the manner in which Iran has proceeded to enrich to 60 percent, starting from near 5 percent enriched material, is innovative, suggesting Iran continues to gain valuable experience in producing HEU, and by extension even WGU. It is practicing breakout under a civilian cover, and also learning to reduce the number of steps that it would need to go from natural uranium to WGU.

Although Iran's process of creating 60 percent enriched uranium is far from ideal, the Iranian process has demonstrated certain advantages over the last several months, including being within its technical reach, recycling the tails down to the level of near two percent enriched or even natural uranium, while producing 5, 20, and 60 percent enriched uranium, and more importantly, practicing multi-step enrichment arrangements key to breaking out. Moreover, the Iranians are experimenting with transferring enriched UF_6 as a gas from one step to the next, instead of having to solidify the intermediate product gas and turn it back into a gas in the next step. All this

experimentation is leading Iran to be more capable of breaking out to produce 90 percent enriched uranium, if the leadership orders its production or moves toward the construction of nuclear weapons. Meanwhile, Iran continues to accumulate 60 percent HEU, which can be used directly in a nuclear explosive or further enriched quickly to weapon-grade in relatively few advanced centrifuges. After all, 60 percent enriched uranium is 99 percent of the way to weapon-grade uranium.

Part 3: Current Breakout Estimates

Because of the growth of stocks of Iran's 20 and 60 percent enriched uranium, breakout timelines have become dangerously short. Iran now has enough 20 and 60 percent enriched uranium to use as feed for the first 25 kilograms of weapon-grade uranium, producing about 10 kg of weapon-grade uranium from the 60 percent stock and 15 kg of weapon-grade uranium from the 20 percent stock. Each weapon-grade uranium stock can be produced in parallel, significantly reducing the timeline for production of 25 kilograms of weapon-grade uranium.

The Institute's breakout calculator is used to estimate the worst-case breakout time, as in previous reports. Currently, under the scenario outlined above, the result is that within about three weeks, Iran could produce its first quantity of 25 kg of weapon-grade uranium.

In the breakout estimate, the following conditions are assumed:

- Enrichment capacity at both the Natanz and Fordow Fuel Enrichment Plants, based on the number of installed centrifuges as drawn from the latest IAEA. With regards to the advanced centrifuges, where achieved enrichment output and breakage rates are less known than that of the IR-1 centrifuges, this calculation treats them as relatively inefficient, particularly regarding the IR-6 centrifuge.[6]
- The total enrichment contribution from advanced centrifuges installed at the PFEP is not included, as their use in a breakout would be complicated and likely would not contribute to reducing breakout timelines. However, one exception is that Iran's stock of 60 percent enriched uranium is taken as further enriched to weapon-grade in the IR-6 and IR-4 production-scale cascades at the PFEP. The production of weapon-grade uranium in the PFEP would proceed in parallel to the further, stepwise enrichment of near 20 percent enriched uranium to weapon-grade uranium, here taken as involving two steps.
- For successive quantities of weapon-grade uranium, only LEU stocks between two and five percent enriched uranium are used, and the enrichment level is taken as 4.5 percent. Stocks of less than 2 percent enriched uranium are not used, since to do so would require additional modifications of the cascades to handle the lower enrichments, likely significantly slowing or contributing only slightly, rather than speeding up breakout timelines.

[6] This essentially leads the estimated enrichment output of the IR-6 and IR-4 to be similar to that of the IR-2m, facilitating the calculation where the IR-6, IR-4, and IR-2m centrifuges can be treated as equivalent.

- Only enriched uranium hexafluoride stocks are used; chemical conversion of other stocks is seen as too time consuming to include in the breakout estimate.
- Iran redeploys or installs additional centrifuges during a breakout. During the first months of the breakout, this estimate considers only the additional deployment of five advanced centrifuge cascades already slated for deployment, including four IR-4 cascades and one IR-6 cascade. During this period, Iran would also be adding IR-1 centrifuge cascades at a rate of two per month and advanced centrifuges at the same rate. Iran may deploy additional IR-2m, IR-4, and IR-6 centrifuges during subsequent months as it ramps up centrifuge production. Iran may also deploy additional types of advanced centrifuges, but this effect is not included in the estimate, as none of the dozen advanced centrifuge types that Iran is testing at the PFEP stands out as Iran's clear centrifuge of choice, and many are assessed as performing extremely poorly.

The result is a worst-case estimate, which likely represents the shortest time to breakout, with longer timelines being possible. Uncertainties include ongoing ones, such as the exact enrichment level of the uranium stock enriched between 2 and 5 percent and operational efficiencies of the advanced centrifuges, particularly the IR-4 and IR-6 cascades.

In this worst-case assessment, Iran would need about one week to enrich its stock of near 20 percent enriched UF_6 to weapon-grade, utilizing the centrifuges in the FEP and PFEP. In parallel, it would need about two weeks to enrich its stock of 60 percent to weapon-grade in the two advanced centrifuge cascades in the PFEP. There is some need for set-up, in the case of the 20 percent feed stock, typically taken as two weeks. With this assumption, the breakout timeline to produce 25 kg of weapon-grade uranium becomes three weeks, about 25 percent shorter than the timeline at the end of the last reporting period. Achieving this first quantity of 25 kg of weapon-grade uranium does not depend on using the up to 5 percent stock of enriched uranium.

The time to produce successive quantities of 25 kg of weapon-grade uranium has also shortened. Using Iran's stock of uranium enriched between two and five percent, the second quantity could be produced in just over two months after the commencement of breakout; the third quantity could be produced in about 3.5 months. The fourth quantity would take six months, as Iran depletes the last of its stock of 2 to 5 percent enriched uranium, requiring it to use natural uranium instead.

Part 4: Centrifuge Manufacturing, Mechanical Testing, and Component Inventory

Iran has augmented centrifuge manufacturing and mechanical testing activities in violation of the JCPOA, while halting IAEA monitoring. Since February, Iran has not provided declarations about its production and inventory of centrifuge rotor tubes, bellows, and rotor assemblies or allowed IAEA verification, as specified in the JCPOA. The IAEA has also "not been able to access the data and recordings collected by its surveillance equipment installed to monitor both the manufacturing of rotor tubes and bellows," and consequently has no ability to take inventory.

The Wall Street Journal reported on November 16 that Iran had resumed production of advanced centrifuge components at the TESA centrifuge manufacturing plant near Karaj, the site of a June sabotage incident via drone strike. The report claimed that Iran has made parts for "at least 170 advanced centrifuges."[7] Iran's re-start of centrifuge manufacturing at the Karaj plant raises concerns about Iran's growing ability to secretly divert centrifuge parts to a clandestine storage location or a new enrichment plant, given the lack of IAEA monitoring at the facility since August.

Since January 2021, Iran has been using an existing workshop at Natanz to conduct mechanical testing of centrifuges, a location the IAEA notes was not listed in the JCPOA. This work is likely not subject to IAEA video surveillance. The IAEA reports that it has not been able to access data and recordings which monitor Iran's mechanical testing of centrifuges at the PFEP and Tehran Research Center, as provided for in the JCPOA.

Further, since February 2021, the IAEA has not been able to verify the number of IR-1 centrifuges Iran withdrew from storage or newly produced to replace broken ones withdrawn from the cascade areas in the enrichment plants. Under Iran's CSA, the IAEA typically knows the quantity of centrifuges withdrawn from the cascade areas due to continuous surveillance of the cascade areas and the fact that broken centrifuges contain small amounts of uranium, but the quantity of centrifuges is not typically given in the reports. This quantity could be substantial during the last several months, depending on the damage caused during the April 11 event at the Natanz FEP, estimated to have damaged 15 cascades of IR-1 centrifuges and three cascades of IR-2m centrifuges, or roughly half of Iran's centrifuges operating at the FEP at the time of the incident.

Part 5: Enriched uranium metal production

In December 2020, Iran informed the IAEA that it would begin producing uranium metal, including uranium metal enriched up to 20 percent, in violation of its JCPOA commitments. Iran is using the uranium metal in civil applications, including for experimental fuel rods for the Tehran Research Reactor (TRR). Iran has no pressing need to develop this fuel or for other civilian activities, lending weight to the concern that Iran is installing the wherewithal to make uranium metal to increase its nuclear weapons capabilities and producing it as a way to practice the manufacture of enriched uranium metal components of nuclear weapons. Prior to 2003, under the Amad Plan, Iran was constructing both pilot and large-scale uranium metallurgy facilities to make nuclear cores and practicing with surrogate materials for weapon-grade uranium.[8]

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[7] 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.

[8] David Albright with Sarah Burkhard and the Good ISIS Team, *Iran's Perilous Pursuit of Nuclear Weapons* (Washington, D.C.: Institute for Science and International Security Press, 2021); David Albright, Sarah Burkhard, and Frank Pabian, "Shahid Mahallati: 'Temporary' Plant for Manufacturing Nuclear Weapon Cores," *Institute for Science and International Security*, April 8, 2020, https://isis-online.org/isis-reports/detail/shahid-mahallati-temporary-plant-for-manufacturing-nuclear-weapon-cores/8.

On February 2, 2021, Iran began producing uranium metal using natural uranium in a laboratory experiment at the Esfahan FPFP. As of August 14, 2021, the IAEA verified that Iran had begun producing enriched uranium metal from 20 percent enriched UF_6. It produced 200 grams of enriched uranium metal, starting with 257 grams of enriched uranium in tetrafluoride form. As Iran used more than 200 grams of enriched uranium metal in subsequent fuel production, it appears that additional near 20 percent enriched uranium metal was produced, although the newest IAEA report does not provide any details on this.

Iran has stated the enriched uranium metal is for use in silicide fuel for the TRR. During this reporting period, Iran produced "two batches of uranium silicide" containing 0.43 kg of uranium enriched to 20 percent. Assuming this is in uranium mass, the uranium silicide contains twice the amount of metal that was reported previously (430 grams compared to 200 grams). On November 2, 2021, the IAEA verified that Iran had "manufactured two fuel plates using uranium silicide." At the time, the fuel plates had not yet undergone quality control.

On October 26, 2021, the Agency verified that the installation of equipment for production of enriched uranium tetrafluoride from uranium hexafluoride at the FPFP, while almost complete, had not progressed since the previous IAEA quarterly report.

At the nearby Uranium Conversion Facility at Esfahan, by the end of May 2021, Iran had finished installing equipment for producing depleted and natural uranium metal. It told the IAEA that the facility was ready to operate with uranium, but no nuclear material had been introduced into the production area.

Part 6: Heavy water, Arak reactor, and Fuel fabrication

The IAEA reports that since February, it has not been able to ascertain the status of Iran's Heavy Water Production Plant (HWPP) or the production and inventory of heavy water. Based on commercial satellite imagery, the IAEA assesses that the HWPP continued to operate during this reporting period.

The IAEA reports that Iran has not pursued construction of the Arak heavy water research reactor, now called the Khondab Heavy Water Research Reactor (KHRR), based on its original design. However, questions remain about the irreversibility of technical modifications carried out to date by Iran's partners in the JCPOA Arak reactor working group. Moreover, as of the current report, a wide range of construction activities were taking place at the reactor, including installation of the refueling machine and control room. In addition, the IAEA reported the completion of the lining of the spent fuel pond and the cold commissioning of the secondary cooling system using original equipment.

Iran has started making enriched uranium fuel for the Arak reactor, in violation of the JCPOA. On September 25, 2021, at the Enriched UO_2 Powder Plant (EUPP) at Esfahan, the IAEA "verified that Iran had converted 103 kg of uranium in the form of UF_6 enriched up to 3.5 % U-235, which had been transferred from Natanz, into UO_2F_2. On 18, 22 and 29 September 2021, the Agency verified

that 105.0 kg of uranium in the form of UO_2F_2 had been transferred to FPFP to be converted into AUC and subsequently to UCF for the production of uranium dioxide powder and to Fuel Manufacturing Plant (FMP) at Esfahan for the production of fuel for the Khondab Heavy Water Research Reactor (KHRR)." On November 13, 2021, UO_2 enriched up to 4 percent had been received at the FMP to manufacture several fuel assemblies for the KHRR.

Part 7: Additional Protocol & JCPOA monitoring

This quarterly report is the third since Iran stopped implementing the AP to its CSA and the JCPOA's additional monitoring arrangements on February 23, 2021. Iran also stopped implementing modified Code 3.1 to the CSA.

The IAEA can no longer carry out daily visits to Iran's enrichment facilities, receive updated declarations, or conduct "complementary access" to sites. It has not "had access to data gathered by on-line enrichment monitors and electronic seals, or access to recordings registered by its installed measurement devices." It no longer receives data and recordings of test stands for conducting quality control tests of advanced centrifuge rotor assemblies, prior to their installation at Natanz and Fordow enrichment plants. It also no longer has information about Iran's production of uranium ore concentrate (UOC) or its transfer to the Esfahan facility for conversion, or about UOC obtained from any other source. Annex I to the IAEA report describes these and other reduced provisions, many of which fall under JCPOA enhanced monitoring provisions.

The IAEA also reports that it cannot verify Iran's JCPOA commitments under Sections D, E, S, and T. The Section T commitments relate to prohibited nuclear weapons developmental activities.

During the reporting period, the IAEA attended one meeting of the Procurement Working Group of the JCPOA Joint Commission, which oversees Iran's imports of nuclear-related equipment. Tehran is likely not complying with the JCPOA's procurement channel provisions, given recent evidence of illicit procurements.[9]

Status of the February 2021 Agreement

On September 12, the IAEA and Iran released a joint statement providing that the "IAEA's inspectors are permitted to service the identified equipment and replace their storage media which will be kept under the joint IAEA and AEOI seals in the Islamic Republic of Iran. The way and

[9] The alleged illicit procurements occurred from 2018 to 2020, raising the possibility that Iran has not been complying all along with the JCPOA procurement channel provisions. Spencer Faragasso and Sarah Burkhard, "Iranian Illicit Procurement Scheme to Acquire Controlled Spectrometry Systems Busted," *Institute for Science and International Security*, September 14, 2021, https://isis-online.org/isis-reports/detail/iranian-illicit-procurement-scheme-to-acquire-controlled-spectrometers. Another set of illicit procurements occurred from 2015 to 2018. See: Simon Mairson and Valerie Lincy, "U.S. Targets Procurement Network Supplying Machine Tools to Iran," *Wisconsin Project on Nuclear Arms Control*, October 21, 2019, https://www.wisconsinproject.org/u-s-targets-procurement-network-supplying-machine-tools-to-iran/.

the timing are agreed by the two sides."[10] The IAEA reports that from September 20 to 22, the IAEA serviced surveillance and monitoring equipment and replaced storage media "at all necessary locations in Iran with the exception of the centrifuge component manufacturing workshop at the TESA Karaj complex…where the agency was not provided with access."

During the last IAEA Board of Governors meeting, on September 27, Iran notified the IAEA for the first time that "in its view the equipment related to the workshop was not included in the 'servicing' referred to in the Joint Statement…" The Director General responded in a letter on September 29 that "the agreement reached...did not in any way exclude certain locations and equipment and that [this] had been very clear in all of the Director General's discussions" with Iran. During October, the IAEA sought access on two occasions "to install new cameras and/or to confirm that the production of centrifuge rotor tubes and bellows had not resumed therein." Iran refused access both times.

Iran next sent a communication to the IAEA that was circulated to all member states reiterating its view about the TESA workshop exception, stating these monitoring commitments were not "legal obligations" and "cannot and should not be considered by the Agency as one of its entitlements." Iran also stated that its authorities were "investigating whether the terrorists (referring to the June 2021 sabotage incident via drone strike) have used the Agency cameras to launch an attack on the complex." It asked for the IAEA's cooperation "including through waiving the cameras immunity to be available for further investigation." The Director General states in his latest report that "Iran has unilaterally interpreted the terms of the Joint Statement to exclude, ex post facto" the TESA facility and emphasizes that it is "indispensable that the agreement covers all facilities and locations in Iran in order to maintain continuity of knowledge…[and] for the Agency to be in a position to resume the necessary verification and monitoring activities in Iran in relation to the JCPOA." The Director General also "categorically rejects the idea that Agency cameras played a role in assisting any third party to launch an attack…" He states that the cameras are "under continuity of knowledge" from the moment they are delivered to the IAEA and later installed. The Director General "has agreed that, if Iran so requested, the Iranian authorities could inspect the cameras in the presence of Agency inspectors."

The IAEA concluded that the "repeated prolongation of the agreement, which has now been in place for around nine months, is becoming a significant challenge to the Agency's ability to restore...continuity of knowledge." The IAEA also states that the absence of cameras at the TESA facility "is seriously affecting the Agency's ability to restore continuity of knowledge at the workshop, which has been widely recognized as essential in relation to a return to the JCPOA."

[10] IAEA Director General, *Verification and Monitoring in the Islamic Republic of Iran in light of United Nations Security Council Resolution 2231 (2015)*, GOV/INF/2021/42, September 12, 2021, https://www.iaea.org/sites/default/files/21/09/govinf2021-42.pdf.