INSTITUTE FOR SCIENCE AND INTERNATIONAL SECURITY

REPORT

Analysis of IAEA Iran Verification and Monitoring Report - September 2021

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This report summarizes and assesses information in the International Atomic Energy Agency's (IAEA's) quarterly safeguards report for September 7, 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).

Overall, the IAEA's latest report shows Iran's rapidly advancing nuclear activities and steps to limit IAEA monitoring, while inspectors have a diminishing ability to detect Iranian diversion of assets to undeclared facilities. The IAEA is sounding an alarm to the international community accordingly.

Preface

The IAEA report is the first update on the status of Iran's uranium enrichment program since a one-month extension of a limited monitoring and verification agreement between the IAEA and Iran ended on June 24, 2021. Iran agreed to continue operating IAEA monitoring equipment and video surveillance at nuclear and nuclear-related sites but provide the data to the IAEA at a later, unspecified date. The agreement was intended to preserve IAEA "continuity of knowledge" of Iran's nuclear program after Tehran halted implementation of the Additional Protocol and JCPOA monitoring arrangements in February 2021. According to the IAEA Director General, "Iran's failure to continue implementing the [extended] agreement of 24 May 2021 is preventing the Agency from servicing the [IAEA's monitoring] equipment and replacing the storage media. This is seriously compromising the Agency's technical capability to maintain continuity of knowledge, which is necessary for the Agency to resume its verification and monitoring of Iran's nuclear-related commitments in the future."

During this reporting period, a key date, August 24, 2021, passed for the IAEA to carry out the required maintenance of agency monitoring equipment. Memory cards and batteries must be replaced at least every three months to ensure continued collection of data. According to the Director General, "the Agency's confidence that it can maintain continuity of knowledge at

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remaining facilities and locations in Iran pertinent to the technical understanding, which was already declining prior to 24 August 2021, has significantly further declined since that date."

Shortly before the IAEA's latest report, IAEA Director General Rafael Grossi attempted to arrange a visit to Iran to discuss the monitoring issues and address longstanding concerns with respect to Iran's Comprehensive Safeguards Agreement (CSA). Iran did not accept the invitation, but did ask Mr. Grossi to come to Tehran after the distribution of two IAEA safeguards reports and growing concern among member states about Iran's steps to limit IAEA oversight while augmenting its nuclear program. Mr. Grossi went to Tehran on September 11, finalizing a last-minute deal arranged by the Russians, with U.S. blessing, for Iran to allow the IAEA to service its cameras and monitoring instruments and continue recording data.[2] At a press conference on September 12, Grossi stated that the servicing will occur during the next few days and was intended to stop "the imminent loss of knowledge."[3]

However, Iran will not provide the IAEA with data collected since February. The IAEA/Iran agreement also does not stipulate that Tehran will engage the IAEA further in resolving the agency's outstanding concerns related to Iran's CSA.[4] Mr. Grossi stated during the press conference that he needs to consult with Iran's new government on the way forward with regard to NPT compliance issues. The latter are discussed in a separate IAEA report, issued also on September 7, titled *NPT (Nuclear Non-Proliferation Treaty) Safeguards Agreement with the Islamic Republic of Iran*. The Institute has analyzed this report separately.[5]

While the agreement on the surveillance equipment is welcome, it is only one of many serious safeguards and verification issues. Iran's agreement to the monitoring measure appears to be intended to ward off a resolution at the September 13-17 IAEA Board of Governors meeting, a resolution that is long overdue because of Iran's other major, long-standing incomplete declarations, safeguards violations, and other types of noncooperation that the IAEA reports have detailed.

Despite recent shortcomings, the IAEA still managed to create a detailed picture of Iran's nuclear advancements during the last three months – a picture that demonstrates a rapidly advancing program with waning oversight.

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[2] Steven Erlanger, "Iran and I.A.E.A. Reach Last-Minute Deal on Nuclear Monitoring," *The New York Times,* September 12, 2021, https://www.nytimes.com/2021/09/12/world/europe/iran-iaea-nuclear-deal.html

[3] "Press Conference with IAEA Director General Rafael Mariano Grossi," September 12, 2021, https://www.youtube.com/watch?v=tgcFMzWkGjk.

[4] "Joint Statement by the Vice-President and the Head of Atomic Energy Organization of the Islamic Republic of Iran and the Director General of the International Atomic Energy Agency," September 12, 2021, https://www.iaea.org/newscenter/pressreleases/joint-statement-by-the-vice-president-and-the-head-of-atomic-energy-organization-of-the-islamic-republic-of-iran-and-the-director-general-of-the-international-atomic-energy-agency.

[5] David Albright, Sarah Burkhard, and Andrea Stricker, "The IAEA's Iran NPT Safeguards Report - September 2021," *Institute for Science and International Security*, September 9, 2021, https://isis-online.org/isis-reports/detail/the-iaeas-iran-npt-safeguards-report-september-2021.

Highlights and Worst-Case Breakout Estimate

- Iran has produced a total of 200 grams of near 20 percent enriched uranium metal, first converting uranium hexafluoride enriched to 20 percent to uranium tetrafluoride and then producing uranium metal. Iran produced 2.42 grams of natural uranium metal during the previous reporting period. Despite its claims of civil use, Iran's development of the wherewithal to make uranium metal as well as the metal itself is concerning because its production is a key step in making nuclear weapons.
- Iran has enough enriched uranium hexafluoride in the form of 2 to 5 percent low enriched uranium (LEU), near 20 percent enriched uranium, and 60 percent enriched uranium, to produce weapon-grade uranium (WGU) for over two nuclear weapons without using any natural uranium as feedstock, a fact that reduces breakout timelines.
- A worst-case breakout estimate, which is defined as the time required to produce enough WGU for one nuclear weapon, is as short as one month. Iran could produce a second significant quantity of WGU in less than three months after breakout commences. It could produce a third quantity in less than five months, where it would need to produce some of the WGU from natural uranium.
- As of August 30, Iran has produced an IAEA-estimated stock of 10 kilograms (kg) of near 60 percent enriched uranium (in uranium mass or U mass). Iran started to produce near 60 percent enriched uranium at the Natanz Pilot Fuel Enrichment Plant (PFEP) on April 17, 2021. The Institute estimates that one "significant quantity" of 60 percent enriched uranium is 40 kg (U mass), roughly enough for one nuclear explosive. As this stock grows, Iran can also more quickly produce WGU for a nuclear explosive.
- Iran has added an additional cascade of advanced centrifuges to enrich uranium to 60 percent U-235. Since August 14, Iran has been using a cascade of IR-4 centrifuges, in addition to a previously enriching cascade of IR-6 centrifuges.
- 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 five percent enriched uranium to 20 percent enriched uranium. As such, Iran is experimenting with multi-step enrichment while seeking to shortcut the process.
- The production rate of 20 percent enriched uranium at the Fordow Fuel Enrichment Plant (FFEP) and PFEP remained constant from the end to the previous reporting period to this reporting period. Iran was using a larger 5 percent feed stock during this reporting period.
- Iran continued to grow its near 20 percent enriched uranium stock in the form of uranium hexafluoride, the chemical form of enriched uranium required in centrifuges. As of August 30, 2021, Iran has an IAEA-estimated stock of 84.3 kg of 20 percent enriched uranium (U mass and in the form of uranium hexafluoride), an increase from the previous reporting period's 62.8 kg of 20 percent enriched uranium in the form of hexafluoride.
- Iran has additional stocks of 20 percent enriched uranium, but they are in chemical forms other than hexafluoride. This stock comprises 34.9 kg of 20 percent uranium, 33 kg of

which Iran produced recently and 1.9 kg which were imported under JCPOA Joint Commission rules. The enriched uranium hexafluoride was sent to the Esfahan Fuel Plate Fabrication Plant (FPFP) and converted into forms for fuel assemblies, intermediate chemical products, and a small amount of liquid and solid scrap. The 20 percent enriched uranium used to make uranium metal was from this 33 kg transfer.

- Using the uranium metal, Iran made 20 percent uranium silicide fuel to manufacture a new type of fuel plate for the Tehran Research Reactor (TRR), but the IAEA reports the uranium silicide "was not suitable for making a fuel plate for the new TRR fuel." 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.
- After months of accumulating a large stockpile of uranium enriched to below 2 percent U-235, Iran has started to alternate feeding cascades at the Natanz Fuel Enrichment Plant (FEP) with up to 2 percent enriched uranium and with natural uranium, producing 5 percent LEU more quickly during the times it used 2 percent LEU as feedstock. This way, Iran succeeded in producing additional 20 and 60 percent uranium stocks while maintaining its large stock of up to 5 percent enriched uranium.
- Overall, Iran is improving its ability to recycle tails from multiple enrichment steps ultimately down to the level of slightly enriched uranium, very close to the enrichment level of natural uranium.
- The previous reporting period had indicated a reduced quantity of enriching centrifuges at the FEP following an April 11 sabotage event involving an explosion, but the number of enriching IR-1 cascades and IR-2m cascades appears to have almost fully recovered. Iran now has 30 cascades of IR-1 centrifuges, six cascades of IR-2m centrifuges, and two cascades of IR-4 centrifuges at the FEP. Of those, 29 IR-1 cascades, five IR-2m cascades, and two IR-4 cascades "were being fed" with uranium, as of August 25, 2021.
- Iran's current enrichment capability is estimated to be about 11,700 separative work units (SWU) per year, compared to 9,300 SWU per year at the end of the last reporting period.
- Iran's total usable stock of below 5 percent LEU remained the same compared to the previous reporting period. The reasons why this stock did not increase include its use as feed into cascades to produce 20 and 60 percent enriched uranium.
- The near 5 percent LEU production during this reporting period, which spanned 96 days at the Natanz FEP, equaled 504.9 kg U mass, or a daily average rate of 5.26 kg (U mass), significantly higher than the previous daily production rate of 2.4 kg U mass, reflecting Iran starting with two percent enriched uranium and additional capacity at Natanz.
- The IAEA report does not discuss 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,[6] 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

[6] "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.

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."

- From the TESA (or TABA) Karaj centrifuge manufacturing facility, the site of a sabotage event in June, Iran provided the IAEA with one destroyed video camera, one severely damaged camera, and two intact cameras, which it had moved to the Atomic Energy Organization of Iran. The IAEA recovered data from three of the cameras and placed them under IAEA seal without further examination. However, "the data storage medium and the recording unit from the destroyed camera were not present among the remnants of that camera." The IAEA asked Iran to locate the storage medium and recording unit and explain their absence. Under the terms of the September 12 agreement, Director General Grossi stated that Iran will permit the re-installation of cameras at the TESA/TABA centrifuge manufacturing facility.[7] Any gaps in coverage, while the cameras were not present at the facility, were not discussed or revealed.
- Given the lengthy period since the IAEA had access to surveillance data, it is likely that serious gaps have developed in that data, particularly concerning centrifuge manufacturing and assembly.
- Even with a new commitment by Iran to permit the IAEA to service its equipment, the verification process may now face serious gaps, possibly irreversibly breaking the IAEA's continuity of knowledge of Iran's nuclear activities, which is so vital to verification.

Part 1: Enriched Uranium Stocks

The IAEA report provides more detail about Iran's LEU stocks than previous reports, at least since the implementation of the JCPOA in early 2016.

At the Natanz FEP, Iran produced approximately 746.9 kg of UF_6 enriched up to 5 percent U-235 during the reporting period, which spans 96 days from May 22, 2021, to August 27, 2021. The report discusses this amount as kilograms of uranium hexafluoride, creating confusion over whether the values represent the uranium mass of the uranium hexafluoride or the mass of both the uranium and hexafluoride, which the authors refer to as hex mass. However, other language in the report indicates that the kilograms of UF_6 enriched up to 5 percent U-235 are in units of hex mass. The total uranium mass would be 505 kilograms, for a monthly production rate of 157.8 kg U mass and a daily production rate of 5.26 kg U mass.

At the FFEP, from May 22, 2021, to August 29, 2021, Iran produced 61.5 kg of UF_6 enriched up to 20 percent enriched uranium, or 41.6 kg U mass. It produced 348.5 kg of UF_6 hex mass (or 235.5 U mass) of up to 2 percent enriched uranium in tails.

[7] "Press Conference with IAEA Director General Rafael Mariano Grossi," September 12, 2021, https://www.youtube.com/watch?v=tgcFMzWkGjk.

At the PFEP, Iran produced 2 percent enriched uranium and up to 60 percent enriched uranium stock. It also produced small amounts of uranium enriched up to 5 percent and up to 20 percent in the PFEP's R&D lines 1 and 4. During this reporting period, the PFEP produced 11.3 kg hex mass of near 60 percent enriched uranium (equivalent of 7.6 kg U mass); 19.2 kg of near 20 percent enriched uranium hex mass (13 kg U mass); 92.6 kg hex mass of up to 5 percent LEU (62.6 kg U mass); and 416.7 kg hex mass of uranium enriched to up to 2 percent U-235 (281.7 kg U mass).

Of the 2 percent enriched uranium, Iran produced 109.6 kg hex mass (74 kg U mass) in PFEP R&D lines 2, 3, and 5, and 307.1 kilograms of UF_6 (207.6 kg U mass) enriched up to 2 percent U-235 as tails in line 1. The latter is estimated to have an average enrichment level of 1 percent.

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 the total amount.

The estimates of additional amounts of LEU in oxides and intermediate products, fuel assemblies and rods, and in scrap, add up to 68.4 kg U mass, almost twice the amount of previous reporting periods. This increase applies mostly to the uranium oxide and intermediate estimate (21.2 kg increase) and the uranium in fuel assemblies and rods (10.6 kg increase), reflecting the 20 percent enriched uranium transferred to the FPFP for production of fuel rods. In total, Iran transferred 33 kg (U mass) of near 20 percent enriched uranium in the form of uranium hexafluoride for manufacturing TRR fuel and for R&D activities on new TRR fuel.

New to this report and the previous report are the masses of enriched uranium feed used to produce higher enriched uranium stockpiles. The IAEA provides the amount of LEU used to make near 20 percent and near 60 percent enriched uranium, which allows for a more realistic estimate of production capability compared to using differences in total stockpiles alone.

Of its near 5 percent LEU stock, Iran fed 444.3 kg hex mass (or 300.3 kg U mass) into the tandem cascades at Fordow, for a feed rate of about 4.5 kg per day hex mass, or 3 kg U mass. It also fed 427.2 kg hex mass (288.8 kg U mass) into PFEP R&D lines 1, 4 and 6. In total, Iran used 871.5 kg hex mass (589.1 kg U mass) as feed to produce 20 and 60 percent enriched uranium, which is up from last reporting period, where it was 540.2 kg hex mass or 365.2 kg U mass.

Of its near 2 percent LEU stock, Iran fed 2090.0 kg hex mass (1412.8 kg U mass) into the FEP.

Based on this information, the new stockpile of near 5 percent LEU in uranium mass should be the sum of 1773.2 kg U mass from the last reporting period, 505 kg from the FEP, and 62.6 kg from the PFEP, with the feed of 589.1 kg subtracted, resulting in 1751.7 kg. This is close, but not exactly equal to the 1774.8 kg U mass of near 5 percent LEU that the IAEA reported.

The net overall enriched uranium stock, including all levels of enrichment and all chemical forms, decreased by 800 kg from 3241 kg U mass to 2441 kg (see Table 1). The near 5 percent LEU stock remained almost constant, and even grew slightly by 1.6 kg, signifying its higher level of

production. The near 2 percent LEU stock decreased by 864 kg to 503.8 kg, the near 20 percent enriched uranium hexafluoride stock increased by 21.5, from 62.8 kg to 84.3 kg (U mass), and the near 60 percent enriched uranium stock comprised 10 kilograms (U mass) or 14.8 kilograms (hex mass). (This is up from 2.4 kg (U mass) at the end of the last reporting period). The remaining discrepancy is due to the increase in uranium in other chemical forms.

The near 5 percent LEU production during this reporting period, which spanned 96 days at the Natanz FEP, equaled 504.9 kg U mass, or a daily average rate of 5.26 kg (U mass), significantly higher than the previous daily production rate of 2.4 kg U mass, reflecting the feeding of two percent enriched uranium and additional capacity at Natanz.

A comparison of near 20 production at Fordow and PFEP shows that production has remained near constant at both during the last four months. The near 20 percent enriched uranium production rate during the previous reporting period at the Fordow FFEP was 41.2 kg (U mass) over 94 days, equaling 0.44 kg per day. The production rate during this recent period was 41.6 kg (U mass) over 98 days (at Fordow only) for a very similar daily production rate. During the previous reporting period, from April 17, 2021 to May 21, 2021, Iran produced 4 kg (U mass) of 20 percent enriched uranium at the PFEP over 34 days, adding 0.12 kg to the daily production, for an average of 0.56 kg (U mass) per day during that time span. During this reporting period, 13 kg (U mass) of 20 percent enriched uranium were produced at the PFEP over the full 98 days, for combined FFEP and PFEP production of 54.6 kg (U mass) of 20 percent enriched uranium. Including this amount, the average production was also 0.56 kg (U mass) per day. At this rate, Iran could produce 16.7 kg of near 20 percent enriched uranium per month (U mass), or 24.7 kg of near 20 percent enriched uranium per month (hex mass). Yearly, Iran could produce 200 kg (U mass) or 296 kg (hex mass).

The 60 percent enriched uranium production rate during this reporting period was 7.6 kg (U mass) over 99 days, resulting in a daily average rate of 0.077 kg (U mass) or an average rate of 2.3 kg/month.

At the end of the previous reporting period, 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. 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 this reporting period, 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. This shows that overall, Iran is improving its ability to recycle its tails, down to the level of one percent enriched uranium.

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

Chemical Form	November 2, 2020	February 16, 2021	May 22, 2021	August 30, 2021
UF_6 (kg)	2408.5	2933.1	3206.3	2,372.9
Uranium oxides and their intermediate products (kg)	15.5	13.3	13.3	34.5
Uranium in fuel assemblies and rods (kg)	8.2	10.5	10.5	21.1
Uranium in liquid and solid scrap (kg)	10.7	10.9	10.9	12.8
Enrichment Level Subtotals				
Uranium enriched to 3.67 percent (kg)	215.1	-	-	-
Uranium enriched up to 5 percent (kg) but more than 2 percent	1535.1	1890	1773.2	1,774.8
Uranium enriched up to 2 percent (kg)	692.7	1025.5	1367.9	503.8
Uranium enriched up to 20 percent (kg) and in the form of UF_6	0	17.6	62.8	84.3
Uranium enriched up to 60 percent (kg)			2.4	10
Uranium in chemical forms other than UF_6 with unspecified enrichment level (kg) (33 kg is near 20 percent enriched uranium).		34.7	34.7	68.4
Totals of Enriched Uranium in UF_6, <5 % (kg)		2915.5	3141.1	2,278.6
Totals of Enriched Uranium in UF_6, including near 20 % and near 60 % (kg)		2933.1	3206.3	2,372.9
Totals of Enriched Uranium in all chemical forms, <5 % <20 % and <60 % enriched	**2442.9**	**2967.8**	**3241**	**2,441.3**

*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 August 25, 2021, in total, 30 cascades of IR-1 centrifuges, six cascades of IR-2m centrifuges, and two cascades of IR-4 centrifuges were installed to enrich natural uranium hexafluoride up to 5 percent. At that time, 29 IR-1 cascades (up from 15 cascades at the end of the previous reporting period), five IR-2m cascades (up from three cascades), and two IR-4 cascades (same amount) were being fed with natural uranium hexafluoride. Compared to the last report, 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.

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 six IR-1 cascades.

The number 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

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 enriched uranium.

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, once completed, will enable Iran to "change the configuration of the cascades more easily."

On August 29, 2021, the IAEA verified that Iran had almost completed the installation of new sub-headers on one of the IR-6 cascades; ten IR-6 centrifuges were installed in the other planned cascade of IR-6 centrifuges, but no new sub-headers had yet been installed.

Pilot Fuel Enrichment Plant

Since the last quarterly report, Iran has not progressed further with a planned transfer of its enrichment research and development activities to a segregated area of Building A1000 at the FEP. Iran has 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. The IAEA report does not provide a start date for this new area. Given its three-fold greater size, one has to ask if this area could be devoted to production-scale enrichment in case of a surge in enriched uranium production or a breakout.

Lines 1, 4, and 6 have been used 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 the previous IAEA report. As of August 28, 2021, Iran was feeding UF_6 enriched up to 5% U-235 into the two cascades in R&D production lines 4 and 6, comprising 153 IR-4 and 164 IR-6 centrifuges, respectively, to produce UF_6 enriched up to 60% U-235 using a new mode of production. The IR-4 cascade in line 4 has an estimated enrichment output of about 500 separative work units per year (SWU/year). The IR-6 cascade in line 6 has a total estimated enrichment output of about 1000 SWU/year. The two lines together have an estimated output of 1500 SWU/year, or the equivalent of about 1667 IR-1 centrifuges.

Iran continued to enrich uranium up to 2 percent in lines 2 and 3 at the above ground PFEP, feeding natural uranium into a whole host of centrifuge types and cascades: nine IR-4 centrifuges; five IR-5 centrifuges; four IR-6 centrifuges, ten IR-6 centrifuges and another cascade of 19 IR-6 centrifuges; three IR-6s centrifuges; and ten IR-s centrifuges.

The following single centrifuges were being tested in lines 2 and 3 with natural uranium but were not accumulating enriched uranium: one IR-1 centrifuge; 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.

Iran was using line 5, which earlier held a production-scale IR-2m cascade, to enrich uranium in a cascade of 18-IR-1 centrifuges and 32 IR-2m centrifuges, producing uranium enriched below 2 percent.

Table 2 lists the estimated enrichment capacity by facility, leading to a current total of 11,694 SWU/year, or the equivalent of 12,994 IR-1 centrifuges. This total number is significantly higher from the previous reporting period's 9297 SWU/year, due to restored enrichment capability after the event at the Natanz FEP. In the table below, it is assumed that only those cascades observed by inspectors to be enriching on August 25, 2021 are operational at Natanz, instead of all the installed cascades, which would be one additional IR-1 cascade and one additional IR-2m cascade. 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. Number of enriching centrifuges and enrichment capacity

	Number of centrifuges	Enrichment capacity in SWU/yr	IR-1 equivalent
Natanz	6035	8557	9507
Fordow	1044	940	1044
Natanz PFEP*	486	2198	2442
Lines 2 & 3	See text		
Lines 1, 4, 5, 6	See text		
Total enriching	**7565**	**11694**	**12994**

*The value for lines 1, 2, 3, and 5 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 and 6 of the PFEP are given in the text. All 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.

Practicing Breakout by Producing 60 Percent Enriched Uranium

During this reporting period, Iran continued to produce 60 percent enriched uranium, or highly enriched uranium (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. Sixty percent enriched uranium can be used directly in nuclear weapons, where the amount needed is about 40 kg (U mass), compared to the 25 kg (U mass) of 90 percent enriched material required. 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 is gaining valuable experience in producing HEU, and by extension even WGU, practicing breakout under a civilian cover, and also learning to reduce the number of steps that it would need to go from natural to WGU.

Although Iran's multi-step process of creating 60 percent enriched uranium is far from ideal, the Iranian process has certain advantages, including being within its technical reach, recycling the tails down to the level of natural uranium, while producing 5, 20, and 60 percent enriched uranium, and more importantly, practicing multi-step enrichment arrangements. Moreover, the Iranians are experimenting with transferring enriched uranium hexafluoride 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 bound to lead 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 just one cascade of advanced centrifuges.

Part 3: Current Breakout Estimates

The Institute's breakout calculator is used to estimate a current worst-case breakout time, based on Iran's LEU and HEU stocks and installed enrichment capacity, post-explosion.

In the breakout estimate, the following conditions are assumed:

- Enrichment capacity at both the Natanz and Fordow Fuel Enrichment Plants, as drawn from the latest IAEA report. This calculation applies an additional inefficiency coefficient of 50 percent to the IR-6 cascade and of 10 percent to the IR-4 cascade, reflecting operational inexperience and breakage.[8]
- 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 an IR-6 or IR-4 cascade, in parallel to the further, stepwise enrichment of up to five and 20 percent enriched uranium hexafluoride stocks.
- Only LEU stocks above 2 percent enriched uranium are used. 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; and
- Iran redeploys or installs additional centrifuges during a breakout. During the first four 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. 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.

Because of uncertainties, only one case is considered in this report, a worst case, which likely represents the shortest time to breakout, with longer timelines being probable. The uncertainties include ongoing ones, such as the exact enrichment level of the enriched uranium stock enriched between 2 and 5 percent. Additional uncertainties concern the operational efficiencies of the advanced centrifuges, particularly the IR-4 and IR-6 cascades.

[8] 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.

In this worst-case assessment, Iran's stock of uranium enriched between 2 and 5 percent is assumed to be all enriched to 4.5 percent.[9] In addition, Iran has a stock of 125 kg of near 20 percent enriched uranium (hex mass) in the form of uranium hexafluoride. (Its stock of near 20 percent in other chemical forms is ignored here). Iran's small stock of 60 percent enriched uranium is also important, leading to the production of approximately five kilograms of WGU in a parallel process to the main breakout.

Under these additional assumptions, Iran's current stock of enriched uranium, as of the end of this reporting period, is sufficient to support the production of enough WGU for over two nuclear weapons. In this new situation, breakout for one nuclear weapon could be accomplished in as little as four weeks, including a two-week setup time. If breakout continued, a second significant quantity of WGU would be produced late in the third month after breakout commences, and a third quantity could be produced in less than five months, where this last quantity would involve the enrichment of some of the WGU from natural uranium. In sum, enough WGU could be produced for three nuclear weapons in just under five months, with the first quantity available after about a month after breakout preparations are instituted.

Part 4: 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 claims the uranium metal will be used in experimental fuel rods for the Tehran Research Reactor (TRR). 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 uranium hexafluoride. It has produced 200 grams of enriched uranium metal, starting with 257 grams of enriched uranium in tetrafluoride form.

The yield indicates an improvement in the process from the first experiment and is consistent with the second experiment, both conducted with natural uranium. During the first experiment on February 8, 2021, Iran gained 3.6 grams metal out of 9.85 grams uranium metal contained in 13 g of UF_4, a yield of less than 40 percent. During the second reporting period, Iran gained 2.42 kg out of 3.1 kg uranium in the form of UF_4, a yield of 78 percent. During this most recent reporting period, the yield was also at 78 percent.

Iran's production of uranium metal could assist it in furthering knowledge relevant to making nuclear weapons under the guise of a peaceful use. Prior to 2003, under the Amad Plan, Iran was

[9] In its report, the IAEA refers to uranium enriched up to 5 percent rather than 4.5 percent, as was done earlier. However, there is no evidence that Iran systematically increased the level of enrichment in its product. We continue to use 4.5 percent as the upper bound of this category of enriched uranium in breakout calculations.

constructing both pilot and large-scale uranium metallurgy facilities to make nuclear cores and practicing with surrogate materials for weapon-grade uranium.[10]

Part 5: Other Information - Heavy water & Arak reactor, Additional Protocol, JCPOA monitoring

Heavy water & Arak reactor

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 informal communication with Iran that it will continue collecting surveillance and data at relevant sites, the agency assumes that beyond June 24, the heavy water monitoring system continues to operate. The IAEA has not had access to the data and recordings collected by its equipment.

The IAEA reports that Iran has not pursued construction of the Arak heavy water research reactor 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.

Suspension of Additional Protocol and JCPOA Monitoring Arrangements

This quarterly report is the second 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 can also no longer reconcile Iran's declarations of the production of centrifuge rotor tubes and bellows prior to February 23 with the current inventory. It no longer receives the data and recordings collected by surveillance equipment at locations where Iran conducts mechanical testing of centrifuges. 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 or its transfer to the Esfahan facility for conversion. An annex to the IAEA report describes these and other reduced provisions, many of which fall under the JCPOA's enhanced monitoring.

[10] 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.

Status of the February Agreement

In February 2021, the IAEA and Iran reached an agreement whereby Iran agreed to continue implementing for three months a limited number of IAEA surveillance and monitoring activities and record and collect data at nuclear and nuclear-related sites, preserving during the life of the agreement the data and video monitoring records. Iran also agreed to continue abiding by its CSA. It is worth noting that under the CSA, the IAEA is still empowered to access any location in Iran relevant to determining the correctness and completeness of Iran's safeguards declaration. It is unclear whether the IAEA intends to invoke this authority. The Director General characterized the temporary agreement as a "stop gap measure" to enable the agency to reconstruct what occurred at Iran's nuclear sites and reconcile its estimates with actual data collected in Iran and avoid losing "essential information."

At the end of the three-month period, Iran agreed to extend the bilateral agreement for another month, until June 24, 2021. Iran threatened to erase the IAEA's surveillance and electronic data if it did not receive sanctions relief by that date. As the deadline approached and passed and nuclear talks did not result in sanctions lifting, Iran did not reply to the IAEA's requests to clarify whether it would continue to collect or retain IAEA data. The IAEA notes that it received only "informal communications" from Iranian authorities that "monitoring and surveillance equipment covered by the technical understanding continued to operate and the information that was collected continued to be stored after 24 June 2021." The Director General stated in the report that "Iran was expected to communicate with the Agency about its position" and that "failure to continue implementing this agreement undermines the Agency's capability to maintain continuity of knowledge and to recover the information collected by its equipment which is necessary to resume its verification and monitoring of Iran's nuclear-related commitments in the future."

After receiving no formal response from Iran in June, the IAEA wrote to Iran on August 16 that the agency needed to access all relevant sites to service equipment before August 24, after which memory cards would reach capacity and batteries would run out. The IAEA requested to access the sites during the period from August 21 to 29 "in order to service the equipment and replace the storage media, which is kept under Agency seal."

The IAEA reported serious concerns about maintaining continuity of knowledge about Iran's activities at its nuclear and nuclear-related sites:

> *...The Agency has not received information from Iran as to the status of the remainder of its monitoring and surveillance equipment in Iran pertinent to the technical understanding. Indeed, Iran has failed to engage with the Agency at all on this matter for a number of months. Iran's failure to continue implementing the agreement of 24 May 2021 is preventing the Agency from servicing the equipment and replacing the storage media. This is seriously compromising the Agency's technical capability to maintain continuity of knowledge, which is necessary for the Agency to resume its verification and monitoring of Iran's nuclear-related commitments in the future. In light of the above, the Agency's confidence that it can maintain continuity of knowledge at remaining facilities and*

locations in Iran pertinent to the technical understanding, which was already declining prior to 24 August 2021, has significantly further declined since that date. The situation needs to be rectified by Iran without delay. According to the Agency's standard safeguards practice, communication between Iran and the Agency on this matter is indispensable.

On September 11, Director General Grossi visited Tehran following an invitation from Iran, to finalize an agreement brokered by Russia, with U.S. and likely European blessing, for Iran to permit the IAEA to service video surveillance equipment and other monitoring devices. The IAEA will service the equipment over the coming week. The IAEA will not have access to data recorded since February.

Missing Camera Footage at the TESA Karaj Centrifuge Manufacturing Workshop

The IAEA reports concerning new information about damaged cameras and missing data at Iran's centrifuge component manufacturing workshop at the TESA Karaj complex. The agency requested access to its monitoring equipment at the site on July 9, following a reported sabotage event on the facility on June 23, which may have involved a drone attack and damage to at least part of the facility. The IAEA indicated to Iran it was essential that "Agency surveillance cameras were reinstalled and operational before the manufacturing of centrifuge rotor tubes and bellows resumed at that location."

Iran responded only on August 30 that the IAEA could view the cameras from the TESA workshop (also called TABA) near Karaj, but they were located at the Atomic Energy Organization of Iran (AEOI). The IAEA requested access "to assess the status of these cameras, to retrieve the data storage media, and to keep these storage media in the custody of Iran under Agency seal."

On September 4, Iran provided the IAEA with access to four cameras that were previously installed at the site. The IAEA found that one camera had been destroyed, one was severely damaged, and two were intact. The IAEA recovered data from three of the cameras and placed them under IAEA seal without further examination. However, "the data storage medium and the recording unit from the destroyed camera were not present among the remnants of that camera…" In a letter to Iran dated September 6, the IAEA "requested Iran to locate the storage medium and the recording unit, and to provide additional information as to the reasons for their absence."

While cameras at the workshop may have been damaged during the June sabotage event, there is no reason for Iran to have removed the two functioning cameras and relocate them to the AEOI. One possibility, since Iran denied a sabotage event or the occurrence of significant damage, is that Iranian officials sought to examine and then conceal evidence of the incident. Another disturbing possibility is that Iran seeks to hide activities at the site relating to centrifuge production or even the transfer of equipment to other locations. The IAEA is concerned that it will not be able to recover "continuity of knowledge over the activities recorded by these cameras." Under the terms of the September 12 agreement with Iran, Iran will permit the IAEA to install replacement cameras at the centrifuge component manufacturing workshop, to continue collecting IAEA data. However,

Iran's actions surrounding the cameras at the workshop raise doubts about its commitment to continue collecting IAEA monitoring data.

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 IAEA will be able to service its relevant recording equipment during the week of September 13 but will not be able to review the data.

For several months, 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, as provided in the JCPOA. Since May, it has not been able to "confirm the operation of the equipment and exchange the storage media for the data and recordings collected."

Further, since February, 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. Because of the CSA, the IAEA typically knows the number of centrifuges that were 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 four 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 attack.

Uranium Ore Production

Since February, Iran has not provided the IAEA with information or access to data relating to its transfer of uranium ore concentrate (UOC) to the uranium conversion facility (UCF) at Esfahan or obtained from any other source. Iran has not provided any information on its production of UOC, which is necessary to maintain continuity of knowledge about Iran's full uranium fuel cycle and detecting any diversion to undeclared facilities. The IAEA has also not had "access to the data and recordings collected by its surveillance equipment installed to monitor the production of UOC." Since May, the IAEA "has not had access to its equipment to confirm its operation and exchange the storage media for the data and recordings collected." The IAEA will be able to service its relevant recording equipment during the week of September 13 but will not be able to review the data.

Diminished IAEA Capacity to Detect Diversion

Combined with outstanding safeguards issues in Iran, discussed in a companion Institute analysis on Iran's non-compliance with its NPT safeguards commitments, the IAEA is sounding clear warning bells about its reduced ability to monitor Iran's complex and growing nuclear program, which notably has unresolved nuclear weapons dimensions. Iran's commitment to maintaining IAEA surveillance and data collection is in serious doubt. In addition, given the lengthy period since the IAEA had access to the data, it is likely that serious gaps have developed in the surveillance data, particularly concerning centrifuge manufacturing and assembly, irreversibly breaking the continuity of knowledge about certain of Iran's centrifuge activities. The IAEA's ability to detect diversion of nuclear materials, equipment, and other capabilities to undeclared facilities has greatly diminished.