Analysis of IAEA Iran Verification and Monitoring Report - September 2022

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

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Background

- This report summarizes and assesses information in the International Atomic Energy Agency's (IAEA) quarterly safeguards report for September 7, 2022, *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).

- Iran's breakout time remains at zero. It has more than enough 60 percent enriched uranium, or highly enriched uranium (HEU) in the form of uranium hexafluoride (UF_6) to directly fashion a nuclear explosive. If Iran wanted to further enrich its 60 percent HEU up to 90 percent weapons-grade uranium (WGU), used in Iran's known nuclear weapons designs, it could do so within a few weeks utilizing only a few advanced centrifuge cascades.

- Iran is learning important lessons in breaking out to nuclear weapons, including by experimenting with skipping typical enrichment steps as it enriches up to 60 percent uranium-235, and building and testing equipment to feed 20 percent enriched uranium and withdraw HEU. 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. It has used temporary feed and withdrawal setups to produce HEU from near 20 percent enriched uranium feed. Iran is also enriching uranium in one IR-6 cascade modified 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.

- Combined with Iran's refusal to resolve outstanding Nuclear Non-Proliferation Treaty (NPT) safeguards violations, the IAEA has a significantly reduced ability to monitor Iran's complex

[1] Andrea Stricker is deputy director of the Foundation for Defense of Democracies' (FDD) Nonproliferation and Biodefense program and an FDD research fellow.

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 remains greatly diminished.

Findings

- Due to the growth of Iran's 60 percent and 20 percent enriched uranium stocks, Iran can now produce enough WGU for three nuclear weapons in one month.
- In addition to being able to use the 60 percent directly or to enrich it to weapon-grade in a few weeks, Iran could produce enough WGU for a second and third nuclear explosive using its existing stock of near 20 percent enriched uranium within a month. Whether or not Iran enriches its HEU up to 90 percent, it can have enough HEU for three nuclear weapons within one month after starting breakout.
- In essence, Iran has effectively broken out slowly by accumulating 60 percent enriched uranium. As of August 21, Iran had a stock of 55.6 kilograms (kg) (in uranium mass or U mass) of near 60 percent enriched uranium in UF_6 form, or 82.2 kg (in hexafluoride mass or hex mass). Iran also has 2 kg of 60 percent HEU in chemical forms other than UF_6.
- Iran keeps two-thirds of its stock of 60 percent HEU at the Esfahan site, where it maintains a capability to make enriched uranium metal. Although Iran has stated that it is using the HEU to make targets for irradiation in the Tehran Research Reactor (TRR), it has converted only a small fraction of its HEU into targets – about 2.1 kg – and has not converted more since March 2022.
- Iran's current production rate of 60 percent enriched uranium is 3.9 kg per month (U mass) using two advanced centrifuge cascades and up to 5 percent low enriched uranium (LEU) as feed.
- Iran is now enriching uranium to 20 percent in both cascades of IR-6 centrifuges at the Fordow Fuel Enrichment Plant (FFEP). It is also operating six IR-1 cascades (three sets of two interconnected cascades) that were already producing 20 percent enriched uranium. The presence of advanced centrifuges at the FFEP enhances Iran's ability to break out using a declared but highly fortified facility.
- The production rate of 20 percent enriched uranium at the FFEP increased by almost 50 percent, from 19.9 kg to 29 kg (U mass) per month, or 29.4 kg and 42 kg (hex mass) per month.
- As of August 21, Iran had an IAEA-estimated stock of 331.9 kg of 20 percent enriched uranium (U mass and in the form of UF_6). Iran also has an additional stock of 30.8 kg (U mass) of 20 percent uranium in other chemical forms.
- At the Natanz Fuel Enrichment Plant (FEP), Iran has installed 36 cascades of IR-1 centrifuges, six cascades of IR-2m centrifuges, two cascades of IR-4 centrifuges, and, newly, three cascades of IR-6 centrifuges. A third IR-4 cascade was still being installed, and newly, four additional IR-2m cascades were being installed.
- Iran's current, total operating enrichment capability is estimated to be about 16,600 separative work units (SWU) per year, compared to 12,600 SWU per year at the end of the last reporting period.

- Average daily production of 5 percent LEU increased accordingly at the FEP, but Iran's total usable stock of below 5 percent LEU continued to decrease, due to the high rate of its use as feedstock at the PFEP and FFEP.
- Iran's overall reported stockpile of LEU continued to rise due to an increase in Iran's stock of up to 2 percent enriched uranium, much of which was produced as tails in the production of 20 percent and 60 percent enriched uranium.
- Since the previous report, a February 2021 agreement between Iran and the IAEA collapsed, which had extended certain JCPOA monitoring measures such as the use of surveillance cameras and safeguards data collection devices. Iran had agreed to continue operating IAEA equipment and collect the information but keep the data in its custody. In June, following an IAEA Board of Governors censure of Iran for non-compliance with its safeguards obligations, Iran demanded the IAEA remove 27 video cameras and other electronic monitoring devices.
- The IAEA reports that it faces serious challenges in re-establishing continuity of knowledge about Iran's activities, such as centrifuge production and production of heavy water. For more than 12 weeks, the IAEA has not been able to monitor Iran's activities, and should it receive past footage and data, has an enormous task to sift through some 1.5 years of video footage. The IAEA also details the remedial measures it will need to take in order to re-establish a centrifuge manufacturing baseline, including access to extensive records.
- The IAEA also faces a gap in knowledge about Iran's advanced centrifuge manufacturing activities at the former TESA Karaj facility from June 2021 until January 2022, raising doubt about its ability to ascertain whether Iran may have diverted centrifuge components.
- The IAEA warns, "Even if all records were provided by Iran, additional safeguards measures were applied by the Agency, and the recovered data proved to be comprehensive and accurate, considerable challenges would remain to confirm the consistency of Iran's declared inventory of centrifuges and heavy water with the situation prior to 21 February 2022."
- The IAEA concludes that "Iran's decision to remove all of the Agency's equipment previously installed in Iran for surveillance and monitoring activities in relation to the JCPOA has also had detrimental implications for the Agency's ability to provide assurance of the peaceful nature of Iran's nuclear programme."

Part 1: Enriched Uranium Stocks

At the Natanz FEP, Iran produced approximately 980.1 kg of UF_6 enriched up to 5 percent U-235 during the reporting period, which spanned 98 days from May 14, 2022 to August 20, 2022. 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 662.5 kilograms, for a monthly average production rate of 202.8 kg U mass and a daily average production rate of 6.8 kg U mass.[2] These average

[2] That production values are reported in uranium hexafluoride mass can be discerned only 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 is in uranium hexafluoride mass.

production rates are up from 170 kg U mass per month or 5.6 kg U mass per day during the previous reporting period. For a "short period," Iran used 2 percent LEU as feed instead of natural uranium, which allows for the quicker production of 5 percent LEU.

At the FFEP, from May 14, 2022 to August 20, 2022, Iran produced 138.5 kg of UF_6 (hex mass) enriched up to 20 percent enriched uranium, or 93.6 kg U mass. It produced 836.7 kg of UF_6 hex mass (or 565.6 kg U mass) of up to 2 percent enriched uranium in tails. The daily average production rate of 20 percent enriched uranium at the FFEP increased by almost 50 percent to 1.4 kg (hex mass) or 0.96 kg (U mass) from the previous reporting period, where it was 0.98 kg (hex mass) or 0.66 kg (U mass). At this rate, Iran could produce 42.4 kg of near 20 percent enriched uranium per month (hex mass) or 28.7 kg (U mass) per month. Annually, Iran could produce 516 kg (hex mass) or 349 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. Iran swapped the numbering for lines 1 and 5 in the PFEP, so that tails from line 4 and 6 are now fed into line 5 rather than line 1. Between May 15, 2022, and August 20, 2022, the PFEP produced 18.5 kg hex mass of near 60 percent enriched uranium (equivalent to 12.5 kg U mass); 327 kg hex mass of up to 5 percent LEU (221.1 kg U mass); and 676 kg hex mass of uranium enriched up to 2 percent U-235 (457 kg U mass).

The 60 percent enriched uranium production rate during this reporting period was 18.5 kg (hex mass) or 12.5 kg (U mass) over 97 days, resulting in a monthly average production rate of 5.7 kg (hex mass) or 3.9kg (U mass), or a daily average production rate of 0.19 kg (hex mass) or 0.13 kg (U mass). This rate is slightly below the previous reporting period's monthly average production rate. Annually, Iran could produce 69.6 kg (hex mass) or 47 kg (U mass) of 60 percent enriched uranium.

Of the 2 percent LEU, Iran produced 183kg hex mass (123.7 kg U mass) in PFEP lines 1, 2, and 3 and 493 kilograms hex mass (333.3 kg U mass) enriched up to 2 percent as tails in line 5.

Due to 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 319.6 kg U mass, close to the amount of the previous reporting period. The report specifies that out of the 319.6 kg enriched to unspecified levels (U mass), 30.8 kg are up to 20 percent LEU and 2 kg are up to 60 percent HEU. According to a footnote in the report, this 20 percent stock decreased by 5.2 kg due to "in-process mixing" with lower enriched uranium.

Of its near 5 percent LEU stock, Iran fed 958.3 kg hex mass (or 647.8 kg U mass) into the cascades at Fordow, for an average feed rate of about 9.9 kg per day hex mass, up from 6.5 kg per day hex mass, or 6.7 kg U mass and 4.4 kg U mass, respectively. This feed rate represents an increase of about 50 percent, in line with the 50 percent increase in 20 percent enriched uranium production. Iran dumped 10.1 kg near 5 percent LEU feed (hex mass), or about 6.8 kg in uranium mass, about one percent of the total feed. It also fed 838.4 kg of near 5 percent hex mass (566.8 kg U mass) into PFEP R&D lines 4, 5, and 6, for a daily average feed rate of 8.6 kg (hex mass) or 5.8 kg U mass per day, similar to the previous reporting period.

Based on this information, Iran's new stockpile of near 5 percent LEU in uranium mass should be the sum of 1055.9 kg U mass from the last reporting period, 662.5 kg from the FEP, and 221.1 kg from the PFEP, with the feed of 1214.6 kg subtracted, resulting in 725.5 kg. Subtracting the 6.8 kg (U mass) dumped at the FFEP, this total becomes 718.7 kg, close to the 713.9 kg U mass of near 5 percent LEU in UF_6 form that the IAEA reported, with the caveat that this time, the IAEA did not report how much near 5 percent LEU exists in forms other than UF_6.

The net overall enriched uranium stock, including all levels of enrichment and all chemical forms, increased by 131.6 kg from 3809kg U mass to 3940.9 kg (see Table 1), a much smaller increase than the 612.3 kg during the last reporting period. This lower increase appears to stem from Iran's efforts to build up its higher enriched uranium stocks rather than its 2 percent enriched uranium stock. The near 5 percent LEU stock in the form of UF_6 continued to decrease by 342 kg, faster than during the previous reporting period. Iran continued to grow its near 2 percent LEU stock, this time by 365.5 instead of the previous reporting period's 764.4 kg, to 2519.9 kg (U mass). The near 20 percent enriched uranium stock increased by 93.5 kg, from 238.41 kg to 331.9 (U mass), and the near 60 percent enriched uranium stock increased by 12.5 kg to 55.6 kg (U mass).

Iran continued to use a combination of R&D lines 4, 5, and 6 to feed 5 percent LEU into lines 4 and 6 to produce 60 percent enriched uranium, while feeding the tails into line 5 to produce 5 percent LEU. During this reporting period, spanning May 15, 2022 to August 20, 2022, of the 838.4 kg (hex mass) of 5 percent LEU fed into lines 4 and 6, Iran turned 18.5 kg (2.2 percent) into 60 percent enriched uranium, 327 kg back into 5 percent enriched uranium (39 percent), and 493 kg (58 percent) remained as tails enriched up to 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	August 30, 2021	November 6, 2021	March 3, 2022	May 15, 2022	August 21, 2022
UF6 (kg)	2372.9	2313.4	2883.2	3809.3	3621.3
Uranium oxides and their intermediate products (kg)	34.5	125.4	249.5	238.9	252.3
Uranium in fuel assemblies and rods (kg)	21.1	35.4	37.8	48.1	48.2
Uranium in liquid and solid scrap (kg)	12.8	15.5	26.6	30.6	19.1
Enrichment Level Subtotals (in UF_6 form)					
Uranium enriched up to 5 percent (kg) but more than 2 percent	1774.8	1622.3	1277.9	1055.9	713.9
Uranium enriched up to 2 percent (kg)	503.8	559.6	1390	2154.4	2519.9
Uranium enriched up to 20 percent (kg)	84.3	113.8	182.1	238.4	331.9
Uranium enriched up to 60 percent (kg)	10	17.7	33.2	43.1	55.6
Enrichment Subtotals (not in UF_6 form)					
Uranium in chemical forms other than UF_6 with unspecified enrichment level (kg) (including 30.8 kg up to 20 % LEU and 2 kg up to 60 % HEU)	68.4	176.3	313.9	317.6	319.6
Totals of Enriched Uranium in UF_6, <5 % (kg)	2278.6	2181.9	2667.9	3210.3	3233.8
Totals of Enriched Uranium in UF_6, including near 20 % and near 60 % (kg)	2372.9	2313.4	2883.2	3491.8	3621.3
Totals of Enriched Uranium in all chemical forms , <5 % <20 % and <60 % enriched	**2441.3**	**2489.7**	**3197.1**	**3809.4**	**3940.9**

*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 31, 2022, in total, 36 cascades of IR-1 centrifuges, six cascades of IR-2m centrifuges, two cascades of IR-4 centrifuges, and two cascades of IR-6 centrifuges were being fed with natural UF_6 and UF_6 enriched up to 2 percent to produce UF_6 enriched up to 5 percent. On September 6, the IAEA verified that Iran had begun feeding a third cascade of IR-6 centrifuges with UF_6 enriched up to 2 percent to produce UF_6 enriched up to 5 percent. During the previous reporting period, 34 IR-1 cascades , six IR-2m cascades, and one IR-4 cascade were being fed with natural UF_6.

The IAEA also reported that on August 31, the installation of four additional, planned IR-2m cascades had begun, the installation of centrifuges in three additional IR-4 cascades had yet to begin, and the installation of sub-headers had been completed for two additional IR-2m cascades.

The quantity of IR-1 or IR-2m centrifuges Iran withdrew from JCPOA-mandated storage is not available for this reporting period because of Iran's refusal since February 2021 to provide the IAEA with access to the data and recordings collected by agency equipment. In general, it is unclear whether the newly installed IR-1 and IR-2m cascades contain newly produced machines or those from storage.

Fordow Fuel Enrichment Plant

Since January 2021, Iran has been using three sets of two interconnected IR-1 cascades, containing 1044 centrifuges, to produce 20 percent enriched uranium from up to 5 percent LEU. On July 7, Iran began feeding 5 percent LEU into a cascade of 166 IR-6 centrifuges with modified subheaders to produce up to 20 percent enriched uranium. On August 31, the IAEA verified that a second IR-6 cascade was also enriching uranium from 5 percent to 20 percent enriched uranium. One IR-1 centrifuge was installed in a separate position and was not being fed.

IR-6 Cascades. As of November 9, 2021, Iran had installed 166 IR-6 centrifuges in the unmodified IR-6 cascade, and in November, started feeding it with up to 5 percent enriched uranium to produce near 20 percent enriched uranium. As of February 23, 2022, Iran had installed 166 IR-6 centrifuges in a second cascade that had been fully modified to allow for more flexible operation such as quickly changing enrichment levels.

On May 24, 2022, Iran was not enriching uranium to 20 percent in the unmodified IR-6 cascade. The modified IR-6 cascade had not yet been fed with uranium. Both were enriching as of the latest report.

On August 31, Iran provided the IAEA with an updated Design Information Questionnaire (DIQ), indicating it planned to install a new product withdrawal line to allow for separate collection of 5 percent LEU made by the two IR-6 cascades and being fed with natural UF6. On September 5, the IAEA verified that the new product withdrawal line had been installed.

Pilot Fuel Enrichment Plant

Since the previous report, Iran has progressed with plans to transfer its enrichment research and development activities to a segregated area of Building A1000 at the FEP, to create a new area of the PFEP. On August 30, the IAEA verified that in preparation for the planned installation of a new feed and withdrawal area for the new enrichment R&D activities, Iran had almost completed the removal of infrastructure and equipment previously used for the same purpose at the FEP.

Iran earlier completed the installation of sub-headers for 18 cascades in this new area, a threefold increase 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. It reported similar findings in previous and current reports. The report does not provide an anticipated 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.

On August 2, Iran informed the IAEA that the PFEP facility operator had interchanged the numbering of R&D lines 1 and 5, but this had no impact on the operating mode. This change is reflected below.

60 Percent Enriched Uranium Production in Lines 4, 5, and 6. Iran continued to use lines 4, 5, and 6 for the production of 60 percent enriched uranium and re-enrichment of tails to 5 percent, 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 August 30, 2022, 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 and up to 164 IR-6 centrifuges, respectively, and producing up to 60 percent enriched uranium. The tails from these two cascades were fed into cascades of IR-5 and IR-6s centrifuges in line 5 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 and the IR-6 cascade in line 6 have a similar estimated enrichment output of about 600 SWU per year each, where the enrichment outputs for these two centrifuge types in a production-scale cascade are taken from separate Institute reports.[3] The two lines together have an estimated output of 1200 SWU per year, or the equivalent of about 1330 IR-1 centrifuges.

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[3] David Albright, Sarah Burkhard, and Spencer Faragasso, "A Comprehensive Survey of Iran's Advanced Centrifuges," *Institute for Science and International Security*, December 2, 2021, https://isisonline.org/isis-reports/detail/a-comprehensive-survey-of-irans-advanced-centrifuges. The enrichment output for the IR-6 is further adjusted based on: David Albright and Sarah Burkhard, "The IR-6 Centrifuge Needs Further Development," *Institute for Science and International Security,* September 9, 2022, https://isis-online.org/isis-reports/detail/the-ir-6-centrifuge-needs-further-development/

Lines 2 and 3. On August 30, the IAEA verified that line 2 and line 3 continued to accumulate uranium enriched up to 2 percent through feeding of natural UF_6. The IAEA verified that Iran had been using, for this purpose, small and intermediate cascades of up to: six IR-2m centrifuges; twenty IR-4 centrifuges; six IR-5 centrifuges; five IR-6 centrifuges, ten IR-6 centrifuges; 20 IR-6 centrifuges; and ten IR-s centrifuges.

The following single centrifuges were being tested with natural UF_6 but not accumulating enriched uranium: five IR-2m centrifuges, two IR-4 centrifuges; three IR-5 centrifuges; three IR-6 centrifuges; one IR-6s centrifuge; one IR-7 centrifuge; one IR-8 centrifuge; one IR-8B centrifuge; and one IR-9 centrifuge.

Last year, Iran implemented a new mode of operation in line 2, 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. For part of last year, only near 20 percent enriched uranium was used as feed, marking the first time Iran started feeding a cascade with uranium enriched higher than 5 percent at any of its enrichment plants. 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. It is possible, and perhaps the objective, that Iran achieved an enrichment level of 90 percent and measured it, prior to remixing with the tails, a measurement likely unavailable to the IAEA. In any case, Iran gained irreversible knowledge in the setup and use of feed equipment designed for smaller quantities and higher enriched uranium levels.

The IAEA reported that as of November 17, 2021, Iran had stopped feeding near 20 percent enriched uranium into line 2. It added that Iran had removed the associated temporary feed and withdrawal setup, a setup likely required because of the smaller quantities of enriched uranium and concerns about criticality of HEU product. The IAEA did not state where this setup is stored or how many such setups exist. These setups could be critically important in a breakout and allow for a more rapid conversion from producing LEU to producing HEU. As such, their use in line 2 represents the use of additional equipment and experience gained relevant to breakout.

Line 1. Iran was feeding natural UF_6 into an intermediate cascade of 18 IR-1 centrifuges and an intermediate cascade of 54 IR-2m centrifuges in line 1 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 that are currently enriching, leading to a total of 16,586 SWU per year, or the equivalent of 18,429 IR-1 centrifuges. This total number is higher than the previous reporting period's 12,572SWU per year. This is because Iran is now enriching uranium in several cascades that were previously installed but not in use, and because Iran added and activated three full IR-6 cascades at the FEP during the last reporting period. For this analysis, the authors lowered the value of the IR-6 enrichment output in a cascade to 3.6, in accordance with our latest assessment of the centrifuge's actual output.[4] Without that adjustment, Iran's overall estimated enrichment capacity would have increased even more compared to the enrichment capacity during the last reporting period. Of note, centrifuge quantities for PFEP line 5 are taken from the November 2021 report, as they are not specified in more recent reports. The total enrichment capacity used in breakout calculations is slightly different. The advanced centrifuges in the PFEP would likely 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. Breakout scenarios and timelines are discussed below.

Table 2. Quantity of enriching centrifuges and enrichment capacity

	Number of enriching centrifuges	**Enrichment capacity in SWU/yr**	**IR-1 equivalent**
Natanz	7964	12426	13807
Fordow	1376	2135	2372
Natanz PFEP*	536	2025	2250
Lines 2 & 3	See text		
Lines 1, 4, 5, 6	See text		
Total	**9876**	**16586**	**18429**

*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, and its stock amounts to well over one significant quantity of HEU. Thus, Iran continues to have enough nuclear explosive material to have assurance it can directly fashion a nuclear explosive device.

Sixty percent enrichment is a level associated with a key step in the traditional A.Q. Khan stepwise process of climbing from natural uranium to 90 percent enriched uranium, or WGU. But 60 percent enriched uranium can be used directly in nuclear weapons. About 40 kg (U mass) is more

[4] David Albright and Sarah Burkhard, "The IR-6 Centrifuge Needs Further Development," *Institute for Science and International Security*, September 9, 2022, https://isis-online.org/isis-reports/detail/the-ir-6-centrifuge-needs-further-development/.

than enough to make a nuclear explosive, compared to 25 kg (U mass) of 90 percent enriched uranium the Institute uses as sufficient for Iran to manufacture a nuclear explosive.

Moreover, the way Iran has proceeded to enrich to 60 percent in one step, starting from near 5 percent enriched material, is innovative, suggesting Iran gained 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.

Iran may have applied this one-step process to the production of small quantities of WGU from near 20 percent enriched uranium, despite not collecting this product. In November 2021, Iran fed an unspecified amount of its near 20 percent enriched uranium stock 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 levels reached may include 90 percent, or weapons-grade.

Although Iran's process of creating 60 percent enriched uranium is far from ideal, the Iranian process has demonstrated certain advantages, including being within its technical reach and 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. More importantly, it is practicing multi-step enrichment arrangements that are 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, if the leadership orders production of WGU 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 weapons-grade in relatively few advanced centrifuges. After all, 60 percent enriched uranium is 99 percent of the way to WGU.

Transfer of 60 Percent from Natanz to Esfahan

During previous reporting periods, Iran transferred 60 percent HEU hexafluoride from the Natanz site to the Fuel Plate Fabrication Plant (FPFP), which it declared to be for the production of HEU targets for the TRR. In January, Iran transferred 23.3 kg (U mass) of 60 percent material to the FPFP. On April 19, 2022, the IAEA verified the receipt of an additional quantity of 15.3 kg (U mass) 60 percent HEU, bringing the total to 38.6 kg (U mass). On August 22, 2022, the IAEA verified the presence of a total of 36.5 kg (U mass) 60 percent HEU at the "storage area" of FPFP. The difference of about 2 kg matches the amount of 60 percent HEU reported to be in forms other than uranium hexafluoride, specified to contain 1.6 kg (U mass) in mini-plates (produced and irradiated in the TRR in March 2022) and 0.4 kg (U mass) in liquid and solid scrap. Given a total stock of 55.6 kg (U mass), about 66 percent of this stock is at Esfahan. Given that Esfahan holds Iran's capabilities to turn enriched uranium hexafluoride into metal, this transfer raises additional proliferation concerns).[5] No additional transfer or production of mini-plates (targets) has been reported since.

Part 3: Current Breakout Estimates

Iran's breakout timeline remains at zero. It has more than enough 60 percent enriched uranium or HEU to be assured it could directly fashion a nuclear explosive.[6] If Iran wanted to further enrich its 60 percent HEU up to weapons-grade, it could do so within weeks utilizing only a few of its advanced centrifuge cascades.[7]

In parallel, within a month, including a setup period, it could produce enough WGU for a second and third nuclear explosive using its existing stock of near 20 percent low enriched uranium. Thus, whether Iran decided to further enrich its 60 percent HEU to WGU or decided to directly use the 60 percent HEU without further enrichment, it could have enough material for three nuclear weapons within one month after starting breakout.

By the end of the second month, Iran could produce enough WGU for a fourth nuclear explosive. Within four months after starting breakout, Iran could accumulate enough for five nuclear weapons. By the fourth month, Iran would be expected to have depleted its near 5 percent LEU stock and would have to enrich from natural uranium. Accordingly, the accumulation for a sixth quantity would take several months longer.

When Iran ended its crash nuclear weapons program in 2003, called the Amad Plan, its biggest bottleneck was its lack of WGU; it still needed at least a few more years to accumulate enough WGU for a nuclear weapon.[8] Under intense international pressure, Iran decided in 2003 to downsize and better camouflage its nuclear weapons effort, while pushing to establish a robust capability to enrich uranium. Today, that decision has borne fruit. While it could only aim for enough nuclear explosive material for five nuclear weapons in 2003, today it can have enough for those five weapons in six months. With its residual and covert nuclear weaponization capabilities, Iran could test a nuclear explosive underground or deploy a crude nuclear weapon within several

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[5] David Albright, Sarah Burkhard, and Andrea Stricker, "Analysis of IAEA Iran Verification and Monitoring Report - May 2022," *Institute for Science and International Security*, June 6, 2022, https://isis-online.org/isis-reports/detail/analysis-of-iaea-iran-verification-and-monitoring-report-may-2022/8

[6] According to the IAEA, Iran has 55.6 kg of 60 percent enriched uranium (uranium mass) in the form of uranium hexafluoride, slightly more than one significant quantity, which the IAEA defines as the "approximate amount of nuclear material for which the possibility of manufacturing a nuclear explosive cannot be excluded."

[7] For background, see David Albright and Sarah Burkhard: "Entering Dangerous, Uncharted Waters: Iran's 60 Percent Highly Enriched Uranium," *Institute for Science and International Security,* April 11, 2022, https://isis-online.org/isis-reports/detail/entering-uncharted-waters-irans-60-percent-highly-enriched-uranium. The Institute's breakout calculator is used to estimate credible, worst-case breakout timelines, as in previous reports. The methodology is described in earlier Institute reports.

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

months – certainly within six months – and deploy nuclear weapons on ballistic missiles within a year or two.

The Institute's breakout calculator is used to estimate the worst-case breakout time, as in previous reports. The methodology is described in earlier Institute reports. The production of WGU from the 20 and any 60 percent enriched uranium stocks can proceed in parallel, significantly reducing the timeline for production of 25 kg of WGU (U mass). The authors' benchmark reflects a reasonable, assured quantity of WGU for a variety of nuclear weapon designs available to Iran and the creation of a pipeline for production of multiple WGU cores. As before, the total enrichment contribution from small cascades of advanced centrifuges installed at the PFEP is not included, as their use in a breakout would be complicated and likely would not contribute significantly to reducing breakout timelines. However, the production-scale cascades of IR-4 and IR-6 centrifuges in line 4 and line 6, respectively, are an exception. In the breakout calculations, Iran's stock of 60 percent enriched uranium is taken as further enriched to weapons-grade in these two cascades. These two cascades are then only included in any effort to enrich five or twenty percent enriched uranium to WGU after the 60 percent HEU stock is depleted, taken as after roughly one month. Any production of WGU in the PFEP would proceed in parallel to the further, stepwise enrichment of 4.5 percent and near 20 percent enriched uranium to WGU at the FEP and FFEP. Stocks of less than 2 percent enriched uranium are not used, since to do so would require additional modifications of the cascades to handle lower enrichments, likely significantly slowing or contributing only slightly, rather than speeding up, breakout timelines. Lastly, only enriched uranium hexafluoride stocks are used; Iran's chemical conversion of other stocks is assessed as too time consuming, and involving too little material, to significantly affect the breakout estimate.

The breakout timelines are credible, worst-case estimates, likely representing the shortest timelines to breakout, with longer timelines 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.

Part 4: Centrifuge Assembly, 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 2021, 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 (see Part 7). 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. From June 9-11, 2022, Iran removed all such surveillance equipment.

One location affected by the June removal involves centrifuge manufacturing operations Iran had moved from the TESA Karaj centrifuge manufacturing plant to Natanz. A separate IAEA report from April 14, 2022 states that on April 4, Iran had moved all machines for production of centrifuge rotor tubes and bellows from the TESA Karaj site – the site of an alleged drone attack in June 2021 – to the FEP at Natanz (see also Part 7).[9]

On August 29, per Iran's request, the agency removed seals that had been attached in December 2021 to one flow forming machine, used for past centrifuge component manufacturing. Typically, Iran has used flow forming machines for making thin-walled maraging steel tubes, which can then be made into bellows. The IAEA has also not been able to confirm the extent to which Iran is continuing to use carbon fiber not subject to previous continuous agency containment and surveillance measures to manufacture rotor tubes.

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 and is in fact banned for such use under the JCPOA. It is unknown if Iran allowed the IAEA to initially subject this new facility to video surveillance. However, the IAEA reports that it has not been able to access data and recordings which monitor Iran's mechanical testing of centrifuges, such as at the PFEP and Tehran Research Center, as provided for in the JCPOA. From June 9-11, 2022, Iran removed IAEA surveillance equipment monitoring mechanical testing.

Iran has constructed a temporary advanced centrifuge assembly workshop at Natanz, possibly in the basement of the administration building at Natanz.[10] This may be the same facility as mentioned above.

Iran is also building a larger, permanent advanced centrifuge assembly facility under a nearby mountain to the south of the Natanz enrichment plants.[11] The facility will replace the above-ground Iran Centrifuge Assembly Center (ICAC), destroyed in an attack in July 2020. The Institute assesses that Iran has recently made significant progress on this tunnel complex, which is likely to be more deeply buried than the Fordow enrichment plant and contain significant floor space.[12]

Iran's relocation of centrifuge manufacturing and assembly facilities from above-ground to highly fortified, underground locations is part of its ongoing effort to render such capabilities immune to sabotage or military strikes.

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[9] Francois Murphy, "Iran moves centrifuge-parts workshop underground at Natanz, IAEA says," Reuters, April 28, 2022, https://www.reuters.com/world/middle-east/iran-set-up-centrifuge-parts-workshop-underground-natanz-iaea-says-2022-04-28/; IAEA Director General, "Verification and Monitoring in the Islamic Republic of Iran in light of United Nations Security Council Resolution 2231 (2015)," GOV/INF/2022/11, April 14, 2022.

[10] David Albright and Sarah Burkhard, "Video Walk-Through of Iran's New Interim Centrifuge Assembly Center," *Institute for Science and International Security*, June 29, 2022, https://isis-online.org/isis-reports/detail/video-walk-through-of-irans-new-interim-centrifuge-assembly-center/8.

[11] David Albright, Sarah Burkhard, and John Hannah, "Iran's Natanz Tunnel Complex: Deeper, Larger than Expected," *Institute for Science and International Security*, January 13, 2022, https://isis-online.org/isis-reports/detail/irans-natanz-tunnel-complex-deeper-larger-than-expected/8.

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

Part 5: Enriched uranium metal production remains halted

During the last three reporting periods, Iran has not produced any uranium metal at the FPFP. On February 28, 2022, the IAEA verified that Iran had converted a remaining 900 grams of uranium in the form of uranium tetrafluoride (UF_4) enriched up to 20 percent, previously intended for production of uranium metal, into U_3O_8. However, its capability to produce uranium metal remains intact.

As of August 22, 2022, the IAEA verified a total of 192 kg (U mass) near 20 percent enriched uranium in the form of UF_6 at the FPFP storage area, in addition to the 60 percent enriched uranium hexafluoride discussed above.

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 to produce experimental fuel rods for the TRR. However, Iran has no pressing need to develop this fuel or to use this material for other civilian activities, lending weight to concern that Iran is installing the wherewithal to make uranium metal to increase its nuclear weapons capabilities and is 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 was practicing with surrogate materials for WGU.[13]

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. Iran stated the enriched uranium metal is for use in silicide fuel for the TRR. 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 February 21, 2022, the IAEA verified that the installation of equipment for the first stage of production of enriched UF_4 from UF_6 at the FPFP, while almost complete, had progressed only slightly. The IAEA noted that on May 17, 2022, installation had been completed but had yet to undergo testing and observed the same as of August 15. No progress was observed on the remaining two stages of the process.

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

At the nearby Uranium Conversion Facility (UCF) at Esfahan, in November 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. On August 30, 2022, the IAEA verified that no nuclear material had been introduced into the production area.

Part 6: Heavy water and Arak reactor

The IAEA reports that since February 2021, due to Iran's reductions of agency monitoring, it has not been able to ascertain the status of Iran's Heavy Water Production Plant (HWPP) nor the production and inventory of heavy water. Based on commercial satellite imagery, the IAEA assesses that parts of the HWPP were shut down for maintenance during the reporting period, leading to reduced operation. The IAEA reports that since June 11, Iran had removed Flow-rate Unattended Monitoring (FLUM) equipment at the HWPP, further limiting its monitoring.

The IAEA reports that, as of August 30, 2022, Iran had 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 pumps installed for the primary cooling system, which had not yet been tested. "Civil construction works" on the equipment airlock were not yet completed. Addition of a second layer of steel plate lining to the spent fuel pond had been completed. The IAEA observed no further progress on the construction of a control room for the refueling machine.

Part 7: Additional Protocol & JCPOA monitoring

Iran stopped implementing the Additional Protocol (AP) to its CSA and the JCPOA's additional monitoring arrangements on February 23, 2021, when it also stopped implementing modified Code 3.1 to the CSA. The IAEA notes, "For more than 18 months Iran has not provided updated declarations and the Agency has not been able to conduct any complementary access under the Additional Protocol to any sites and locations in Iran." The IAEA reports that its "verification and monitoring activities have been seriously affected as a result…" The IAEA concludes that "Iran's decision to remove all of the Agency's equipment previously installed in Iran for surveillance and monitoring activities in relation to the JCPOA has also had detrimental implications for the Agency's ability to provide assurance of the peaceful nature of Iran's nuclear programme."

Due to Iran's refusal to implement the AP, 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." In addition to the centrifuge manufacturing limitations described in part 4, the IAEA also 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 development activities.

During the reporting period, the IAEA did not attend any meetings 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 evidence of illicit procurements.[14]

February 2021 Agreement Collapse and Issues with Re-establishing Continuity of Knowledge

Between February 21, 2021 and June 8, 2022, the IAEA and Iran had agreed that Iran would continue to collect safeguards information on agency monitoring and surveillance equipment per the terms of the JCPOA. This would allow the IAEA to "recover and re-establish the necessary continuity of knowledge." Following a request from Iran on June 8, from June 9-11, the IAEA removed all such surveillance and monitoring equipment. In total, the IAEA removed 27 cameras, the on-line enrichment monitor (OLEM) at the FEP, and the FLUM equipment installed at the HWPP. All the equipment was placed under agency seals in Iran.

The IAEA reports that due to the passage of 12 weeks since the removal of this equipment, the agency "would need to take remedial action" to "be able to re-establish continuity of knowledge of Iran's nuclear-related activities during the period…" It "would need to apply additional safeguards measures, including under the AP, and Iran would need to provide all related records to the Agency, the consistency of which the Agency would then need to confirm." The IAEA would "need to determine the comprehensiveness and accuracy of the data recorded by its surveillance equipment between 21 February 2021 and 8 June 2022, currently under Agency seal in Iran." The IAEA notes further, "Even if all records were provided by Iran, additional safeguards measures were applied by the Agency, and the recovered data proved to be comprehensive and accurate, considerable challenges would remain to confirm the consistency of Iran's declared inventory of centrifuges and heavy water with the situation prior to 21 February 2022."

[14] 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. See: 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 IAEA again does not report whether Iran has ever turned over to the IAEA a missing recording unit and storage data from a camera that was destroyed at the TESA Karaj centrifuge manufacturing facility, covering the period February until June 2021. The IAEA faces a gap in knowledge about Iran's advanced centrifuge manufacturing activities from June 2021 until January 2022, raising doubt about its ability to exclude Iran's diversion of centrifuge equipment to a clandestine facility.