INSTITUTE FOR SCIENCE AND INTERNATIONAL SECURITY

REPORT

Analysis of IAEA Iran Verification and Monitoring Report - May 2022

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This report summarizes and assesses information in the International Atomic Energy Agency's (IAEA) quarterly safeguards report for May 30, 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).

The IAEA's latest report details Iran's rapidly advancing nuclear activities and inspectors' diminished ability to detect Iranian diversion of assets to undeclared facilities.

Highlights and Breakout Estimate

- Due to the growth of Iran's 60 percent enriched uranium stocks, Iran has crossed a dangerous new threshold: its breakout timeline is now at zero. It has enough 60 percent enriched uranium, or highly enriched uranium (HEU) in the form of uranium hexafluoride (UF_6) to be assured it could fashion directly a nuclear explosive. If Iran wanted to further enrich its 60 percent HEU up to 90 percent HEU, typically called weapon-grade uranium (WGU), used in Iran's known nuclear weapons designs, it could do so within weeks utilizing only a few advanced centrifuge cascades. In parallel, within a month, including a setup period, Iran could produce enough WGU for a second nuclear explosive from its existing stock of near 20 percent enriched uranium. Whether or not Iran enriches its HEU up to 90 percent, it can have enough HEU for two nuclear weapons within one month after starting breakout.
- Within 1.5 months after starting breakout, Iran could accumulate enough WGU for a third nuclear weapon, using its remaining near 20 percent enriched uranium and some of its 4.5 percent enriched uranium. In 2.75 months after starting breakout, it could have a fourth quantity by further enriching 4.5 percent enriched uranium up to 90 percent. At six months, it could have produced a fifth quantity by further enriching both 4.5 percent enriched uranium and natural uranium.
- In essence, Iran has effectively broken out slowly by accumulating 60 percent enriched uranium. As of May 15, Iran had a stock of 43.1 kilograms (kg) (in uranium mass or U mass)

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of near 60 percent enriched uranium in UF_6 form, or 63.8 kg (in hexafluoride mass or hex mass). Iran also has 2 kg of 60 percent HEU in chemical forms other than UF_6.

- Iran has moved 90 percent of its stock of 60 percent HEU to 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 is unlikely to convert much more.
- Iran's current production rate of 60 percent enriched uranium is 4.3 kg per month (U mass) using two advanced centrifuge cascades and up to 5 percent low enriched uranium (LEU) as feed.
- 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 implementing a plan to allow IR-6 cascades to switch more easily from the production of 5 percent enriched uranium to 20 percent enriched uranium. As such, Iran is experimenting with multi-step enrichment while seeking to shortcut the process.
- Iran is currently not enriching uranium to 20 percent in one cascade of IR-6 centrifuges at the Fordow Fuel Enrichment Plant (FFEP), a cascade that was active during prior reporting periods. Iran has installed a second cascade of 166 IR-6 centrifuges at the FFEP, but still has not yet fed it with UF_6. It also has six IR-1 cascades (three sets of two interconnected cascades) that were already producing 20 percent enriched uranium. The installation 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 remained fairly steady at 19.9 kg (U mass) per month or 29.4 kg (hex mass) per month.
- As of May 15, Iran had an IAEA-estimated stock of 238.4 kg of 20 percent enriched uranium (U mass and in the form of UF_6), an increase over the previous reporting period's 182.1 kg. Iran also has an additional stock of 35.9 kg (U mass) of 20 percent uranium in other chemical forms.
- As with the previous reporting period, Iran has not produced any uranium metal.
- At the Natanz Fuel Enrichment Plant (FEP), Iran has installed 36 cascades of IR-1 centrifuges, six cascades of IR-2m centrifuges, and two cascades of IR-4 centrifuges. Of those, 31 IR-1 cascades, six IR-2m cascades, and one IR-4 cascade were being fed with uranium. A third IR-4 cascade was being installed.
- Iran's current, total operating enrichment capability is estimated to be about 12,600 separative work units (SWU) per year, compared to 13,400 SWU per year at the end of the last reporting period.

- Average daily production of 5 percent LEU remained steady at the FEP, but Iran's total usable stock of below 5 percent LEU continued to decrease, due to the increased rate of its use as feedstock at the PFEP and FFEP.
- Iran's overall reported stockpile of LEU increased due to a significant 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.
- In its latest report, the IAEA states that "prior to the end of March 2022, the Agency replaced all of the storage media in JCPOA-related cameras," including those at Iran's new or temporary centrifuge manufacturing and assembly facilities. The IAEA will not have access to video recordings and data, which Iran claims it will keep in its custody, until it receives relief from sanctions. The IAEA, for more than one year, has not been able to monitor Iran's production of advanced centrifuges, particularly rotors and bellows, per JCPOA monitoring provisions, and faces a difficult challenge in reconstructing events should Iran turn over these data.
- The IAEA also faces a gap in knowledge about Iran's advanced centrifuge manufacturing activities from June 2021 until January 2022, raising doubt about its ability to ascertain whether Iran may have diverted centrifuge components.
- Combined with Iran's refusal to resolve outstanding safeguards violations, the IAEA has a significantly reduced ability to monitor Iran's complex and growing nuclear program, which notably has unresolved nuclear weapons dimensions. The IAEA's ability to detect diversion of nuclear materials, equipment, and other capabilities to undeclared facilities remains greatly diminished.

Part 1: Enriched Uranium Stocks

At the Natanz FEP, Iran produced approximately 718.1 kg of UF_6 enriched up to 5 percent U-235 during the reporting period, which spanned 85 days from February 18, 2022 to May 14, 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 485 kilograms, for a monthly average production rate of 170 kg U mass and a daily average production rate of 5.6 kg U mass, very close to the last reporting period's average production rates.[2]

At the FFEP, from February 18, 2022 to May 14, 2022, Iran produced 83.3 kg of UF_6 (hex mass) enriched up to 20 percent enriched uranium, or 56.3 kg U mass. It produced 470.2 kg of UF_6 hex mass (or 317.9 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 remained constant from the previous reporting period, at 0.98 kg (hex mass) or 0.66 kg (U mass). At this rate, Iran could produce 29.4

[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.

kg of near 20 percent enriched uranium per month (hex mass) or 19.9 kg (U mass) per month. Annually, Iran could produce 358 kg (hex mass) or 242 kg (U mass).

At the PFEP, Iran produced 2 percent enriched uranium, up to 5 percent enriched uranium, and up to 60 percent enriched uranium stock during the reporting period. It did not produce any 20 percent enriched uranium at the PFEP. Between February 19, 2022 and May 14, 2022, the PFEP produced 17.8 kg hex mass of near 60 percent enriched uranium (equivalent to 12 kg U mass); 229 kg hex mass of up to 5 percent LEU (154.8 kg U mass); and 476.96 kg hex mass of uranium enriched up to 2 percent U-235 (322.4 kg U mass).

The 60 percent enriched uranium production rate during this reporting period was 17.8 kg (hex mass) or 12 kg (U mass) over 85 days, resulting in a monthly average production rate of 6.3 kg (hex mass) or 4.2 kg (U mass), or a daily average production rate of 0.211 kg (hex mass) or 0.142 kg (U mass). This rate is very close to the previous reporting period's monthly average production rate. Annually, Iran could produce 77 kg (hex mass) or 52 kg (U mass) of 60 percent enriched uranium.

Of the 2 percent LEU, Iran produced 185.3 kg hex mass (125.3 kg U mass) in PFEP lines 2, 3, and 5, and 476.9 kilograms hex mass (322.4 kg U mass) enriched up to 2 percent as tails in line 1.

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 317.6 kg U mass, close to the amount of the previous reporting period. The report specifies that out of the 317.6 kg enriched to unspecified levels (U mass), 35.9 kg are up to 20 percent LEU and 2 kg are up to 60 percent HEU.

Of its near 5 percent LEU stock, Iran fed 555.3 kg hex mass (or 375.4 kg U mass) into the cascades at Fordow, for an average feed rate of about 6.5 kg per day hex mass, or 4.4 kg U mass. It dumped 1.7 kg near 5 percent LEU feed (hex mass), or about 1.1 kg in uranium mass, representing less than one percent of the total feed. It also fed 722.5 kg of near 5 percent hex mass (488.4 kg U mass) into PFEP R&D lines 1, 4, and 6, for a daily average feed rate of 8.5 kg (hex mass) or 5.7 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 1277.9 kg U mass from the last reporting period, 485 kg from the FEP, and 154.8 kg from the PFEP, with the feed of 863.8 kg subtracted, resulting in 1054.1 kg. Subtracting the 1.1 kg (U mass) dumped at the FFEP, this total becomes 1053 kg, almost matching the 1055.9 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 612.3 kg from 3197 kg U mass to 3809 kg (see Table 1), a similar increase as during

the last reporting period, resulting from overall similar production rates, and largely driven by the increase in up to 2 percent LEU. The near 5 percent LEU stock in the form of UF_6 continued to decrease by 222 kg, slightly faster than during the previous reporting period, considering the differences in timespan. Iran continued to grow its near 2 percent LEU stock, this time by 764.4 kg, to 2154.4 kg (U mass). The near 20 percent enriched uranium stock increased by 56.3 kg, from 182.1 kg to 238.41 kg (U mass), and the near 60 percent enriched uranium stock increased by 9.9 kg to 43.1 kg (U mass).

Iran continued to use a combination of R&D lines 1, 4, and 6 to feed 5 percent LEU into lines 4 and 6 to produce 60 percent enriched uranium, while feeding the tails into line 1 to produce 5 percent LEU. During this reporting period, spanning February 19, 2022 to May 14, 2022, of the 722.5 kg (hex mass) of 5 percent LEU fed into lines 4 and 6, Iran turned 17.8 kg (2.5 percent) into 60 percent enriched uranium, 229 kg back into 5 percent enriched uranium (31.6 percent), and 476.9.3 kg (66 percent) remained as tails enriched up to 2 percent.

During the previous reporting period, spanning November 6, 2021 to February 18, 2022, Iran turned 2.6 percent of the 5 percent feed into 60 percent enriched uranium, 41 percent back into 5 percent enriched uranium, and 57 percent remained as tails enriched up to 2 percent. The product to feed ratio for the 60 percent production thus decreased slightly.

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	May 22, 2021	August 30, 2021	November 6, 2021	March 3, 2022	May 15, 2022
UF6 (kg)	3206.3	2372.9	2313.4	2883.2	3809.3
Uranium oxides and their intermediate products (kg)	13.3	34.5	125.4	249.5	238.9
Uranium in fuel assemblies and rods (kg)	10.5	21.1	35.4	37.8	48.1
Uranium in liquid and solid scrap (kg)	10.9	12.8	15.5	26.6	30.6
Enrichment Level Subtotals (in UF_6 form)					
Uranium enriched to 3.67 percent (kg)	N/A	N/A	N/A	N/A	N/A
Uranium enriched up to 5 percent (kg) but more than 2 percent	1773.2	1774.8	1622.3	1277.9	1055.9
Uranium enriched up to 2 percent (kg)	1367.9	503.8	559.6	1390	2154.4
Uranium enriched up to 20 percent (kg)	62.8	84.3	113.8	182.1	238.4
Uranium enriched up to 60 percent (kg)	2.4	10	17.7	33.2	43.1
Enrichment Subtotals (not in UF_6 form)					
Uranium in chemical forms other than UF6 with unspecified enrichment level (kg) (including 35.9 kg up to 20 % LEU and 2 kg up to 60 % HEU)	34.7	68.4	176.3	313.9	317.6
Totals of Enriched Uranium in UF_6, <5 % (kg)	3141.1	2278.6	2181.9	2667.9	3210.3
Totals of Enriched Uranium in UF_6, including near 20 % and near 60 % (kg)	3206.3	2372.9	2313.4	2883.2	3491.8
Totals of Enriched Uranium in all chemical forms , <5 % <20 % and <60 % enriched	**3241**	**2441.3**	**2489.7**	**3197.1**	**3809.4**

*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 May 23, 2022, in total, 36 cascades of IR-1 centrifuges, six cascades of IR-2m centrifuges, and two cascades of IR-4 centrifuges were installed to enrich natural UF_6 up to 5 percent. At that time, 34 IR-1 cascades (up from 31 cascades at the end of the previous reporting period), six IR-2m cascades (same amount), and one IR-4 cascade (down from two cascades at end of previous period) were being fed with natural UF_6. The IAEA also reported that the installation of one of four additional, planned IR-4 cascades had begun, but the installation of the other three IR-4 cascades and one planned IR-6 cascade had yet to begin.

The quantity of IR-1 centrifuges Iran withdrew from JCPOA-mandated storage is not available for this reporting period because of Iran's refusal since February 2021 to provide the IAEA with access to the data and recordings collected by agency equipment.

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. One IR-1 centrifuge was installed in a separate position.

IR-6 Cascades. During the first half of 2021, Iran announced that it would install two IR-6 cascades to produce five percent feed for the tandem IR-1 cascades in the FFEP. 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 entail feeding natural UF_6 to produce UF_6 enriched up to 5 percent U-235 or feeding UF_6 enriched up to 5 percent U-235 to produce UF_6 enriched up to 20 percent U-235. The modification to the sub-headers of the two IR-6 cascades will enable Iran to "change the configuration of the cascades more easily." The modifications were completed on the "second cascade" by October 12, 2021. Iran also informed the IAEA at that time that the first cascade would not be modified, but remain in its original, fixed configuration.

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 the second, modified cascade. This second cascade had been fully modified to allow for more flexible operation.

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.

Pilot Fuel Enrichment Plant

Iran has not progressed further with earlier plans to transfer its enrichment research and development activities to a segregated area of Building A1000 at the FEP. Iran earlier completed the installation of sub-headers for 18 cascades in this new area, 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.

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

On May 25, 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 the cascades of IR-5 and IR-6s centrifuges in line 1 to produce up to 5 percent enriched uranium. The assay of the tails is likely about 2-3 percent.

The IR-4 cascade in line 4 has an estimated enrichment output of about 607 SWU per year, and the IR-6 cascade in line 6 has a total estimated enrichment output of about 870 SWU per year, where the enrichment outputs of these two centrifuge types in production-scale cascades are taken from a separate Institute report.[3] The two lines together have an estimated output of 1477 SWU per year, or the equivalent of about 1768 IR-1 centrifuges.

Lines 2 and 3. 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

[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

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.

According to the IAEA, line 2 (from November 17, 2021) and line 3 (since the beginning of the previous reporting period) continued to accumulate uranium enriched up to 2 percent through feeding of natural uranium hexafluoride. On May 25, 2022, the IAEA verified that Iran had been using, for this purpose, single cascades of up to: eleven IR-4 centrifuges; six IR-5 centrifuges; ten IR-6 centrifuges, (two cascades of) five IR-6 centrifuges; 19 IR-6 centrifuges; and ten IR-s centrifuges.

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

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

Capacity of Centrifuges Enriching Uranium

Table 2 lists the estimated enrichment capacity by facility for those centrifuges enriching, leading to a total of 12,572 SWU per year, or the equivalent of 13,969 IR-1 centrifuges. This total number is slightly lower than the previous reporting period's 13,402 SWU per year, even though the number of IR-1 cascades enriching at Natanz increased from 31 to 34 cascades. This is because the estimate includes only those cascades inspectors observed to be enriching in May 2022, instead of all the cascades that are installed or all the cascades Iran used to enrich during the previous reporting period, which would include two additional IR-1 cascades, one IR-4 cascade at Natanz, and the two IR-6 cascades at Fordow. Centrifuge numbers for PFEP line 1 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 and higher in this case, since for breakout, also installed but not enriching cascades are included. Further, 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 enriched centrifuges and enrichment capacity

	Number of enriching centrifuges	Enrichment capacity in SWU/yr	IR-1 equivalent
Natanz	6950	9665	10739
Fordow	1044	940	1044
Natanz PFEP*	504	1967	2186
Lines 2 & 3	See text		
Lines 1, 4, 5, 6	See text		
Total	**8498**	**12572**	**13969**

*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, reaching a new milestone of accumulating over one significant quantity of HEU. For the first time, Iran now has 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 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. Up until November 17, 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 weapon-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 weapon-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

Iran has been transferring 60 percent HEU hexafluoride from the Natanz site to the Fuel Plate Fabrication Plant (FPFP). 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). Given a total stock of 43.1 kg (U mass), about 90 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 (see also below).

Target Production. According to the IAEA report, on February 25, 2022, the IAEA received an updated design information questionnaire (DIQ) for the FPFP to enable the production of mini-plates (targets) using 60 percent enriched uranium. The process declared by Iran for manufacturing targets using HEU enriched up to 60 percent is identical to that used for uranium enriched up to 20 percent U-235. On February 28, 2022, the IAEA verified that Iran had begun the conversion of 60 percent enriched uranium in the form of uranium hexafluoride into UO_2F_2. From 2.1 kg (U mass) of HEU in the form of uranium hexafluoride, Iran produced 1.7 kg of uranium in the form of U_3O_8. Between March 11 and 19, 2022, the IAEA verified that Iran had produced at the FPFP 264 HEU targets, each containing about 5.8 grams, containing a total of 1.6 kg of uranium enriched up to 60 percent.[4] All of these targets were shipped to the TRR.

Although Iran has sent a total of 38.6 kg of 60 percent enriched uranium (U mass) to the FPFP, it is expected that only a tiny fraction will be converted into targets. During this reporting period, no further 60 percent material in hexafluoride form was converted at the FPFP. The TRR is unlikely to be able to use that much HEU in targets, given the reactor's small size. As a result, the production of targets will not remove the proliferation and breakout risks posed by Iran's growing stockpile of

[4] 264 targets containing 5.8 grams uranium enriched up to 60 percent account for 1.53 kilograms 60 percent HEU. The reason for the value of 1.6 kg, admittedly a small difference, is not explained, although a possible explanation is that on average more than 5.8 grams is loaded into each target.

HEU. In addition, the Esfahan site is where Iran has put in place a capability to convert enriched uranium into metal, meaning the transfer of this HEU stock to Esfahan increases proliferation risks. As a result, Iran's target program for HEU should be viewed as a cynical attempt by Iran to place a civilian mask on an inherently military material and lay a precedent for future production of HEU.

Part 3: Current Breakout Estimates

Iran has crossed a dangerous new threshold: its breakout timeline is now at zero. It has enough 60 percent enriched uranium or HEU to be assured it could directly fashion a nuclear explosive.[5] If Iran wanted to further enrich its 60 percent HEU up to weapon-grade HEU, it could do so within weeks utilizing only a few of its advanced centrifuge cascades.[6]

In parallel, within a month, including a setup period, it could produce enough WGU for a second nuclear explosive using its existing stock of near 20 percent low enriched uranium. Whether or not Iran enriches its HEU up to 90 percent, it can have enough HEU for two nuclear weapons within one month after starting breakout.

Within 1.5 months after starting breakout, Iran could accumulate enough for a third nuclear weapon, using its remaining near 20 percent enriched uranium and some of its 4.5 percent enriched uranium. In 2.75 months after starting breakout, it could have a fourth quantity by further enriching 4.5 percent enriched uranium up to 90 percent. At six months, it could have produced a fifth quantity by further enriching both 4.5 percent enriched uranium and natural uranium. 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.[7] 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 yearn 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 months – certainly within six months – and deploy nuclear weapons on ballistic missiles within a year or two.

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[5] According to the IAEA, Iran has 43.1 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."

[6] For background, see David Albright and Sarah Burkhard: "Entering Dangerous, Uncharted Waters: Iran's 60 Percent Highly Enriched Uranium," 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.

[7] 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).

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, one exception is that Iran's stock of 60 percent enriched uranium is taken as further enriched to weapon-grade in the IR-6 and IR-4 production-scale cascades at the PFEP, and these cascades are not included in any effort to enrich five or twenty percent enriched uranium to WGU. 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. 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. 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 affect significantly 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.

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 by the JCPOA. It is unknown if Iran allowed the IAEA to 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.

Iran has constructed a temporary advanced centrifuge assembly workshop at Natanz, possibly in the basement of the administration building at Natanz.[8] This may be the same facility as mentioned in the previous paragraph.

Iran is also building a larger, permanent advanced centrifuge assembly facility under a nearby mountain to the south of the Natanz enrichment plants.[9] 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.[10]

Iran has also moved centrifuge manufacturing operations from the TESA Karaj centrifuge manufacturing plant to Natanz. A separate IAEA report from April 14 states that on April 4, Iran 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).[11]

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.

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

[8] Forthcoming Institute report.

[9] 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

[10] 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

[11] 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.

Part 5: Enriched uranium metal production halted

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.[12]

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 production of enriched uranium tetrafluoride from uranium hexafluoride at the FPFP, while almost complete, had progressed only slightly. The IAEA notes that on May 17, 2022, installation had been completed but had yet to undergo testing.

At the nearby Uranium Conversion Facility at Esfahan, by the end of May 2021, Iran had finished installing equipment for producing depleted and natural uranium metal. It told the IAEA that the facility was ready to operate with uranium, but no nuclear material had been introduced into the production area. On February 12, 2022, the IAEA verified that no nuclear material had been introduced into the production area.

During the last two reporting periods, Iran has not produced any uranium metal. On February 28, 2022, the IAEA verified that Iran had converted the remaining 900 grams of uranium in the form of 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.

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

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

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 the HWPP continued to operate during this reporting period.

The IAEA reports that, as of May 11, 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 ongoing "civil construction works" on the equipment airlock, which is almost complete, and the start of adding a second layer of steel plate lining to the spent fuel pond. No further progress was observed on the construction of the control room for the refueling machine.

Last fall, Iran began making enriched uranium fuel for the Arak reactor in violation of the JCPOA. On September 25, 2021, at the Enriched UO_2 Powder Plant (EUPP) at Esfahan, the IAEA "verified that Iran had converted 103 kg of uranium in the form of UF_6 enriched up to 3.5 % U-235, transferred from Natanz, into UO_2F_2. On September 18, 22, and 29, "the Agency verified that 105.0 kg of uranium in the form of UO_2F_2 had been transferred to FPFP to be converted into [ammonium uranyl carbonate] AUC and subsequently to [the Uranium Conversion Facility or] UCF for the production of uranium dioxide powder and to Fuel Manufacturing Plant (FMP) at Esfahan for the production of fuel for the Khondab Heavy Water Research Reactor (KHRR)." On November 13, the FMP received UO_2 enriched up to 4 percent to manufacture several fuel assemblies for the KHRR.

In a previous report, the IAEA reported that on November 21, 2021, it "verified the receipt at [the] EUPP from FEP of 141.1 kg of uranium in the form of UF6 enriched up to 3.5% U-235, of which 139.7 had been converted in December 2021 into UO2F2." The IAEA reported, "In December 2021, the Agency verified that 134.7 kg of uranium in the form of UO_2F_2 had been transferred to FPFP to be converted into AUC, which had subsequently been transferred to UCF for the production of UO2 powder and to FMP for the production of fuel for KHRR." On December 19, "the Agency also verified at EUPP the receipt of 143.1 kg of uranium in the form of UF_6 enriched up to 3.5% U-235 from FEP" and has until now kept this nuclear material under agency seal. During the reporting period, Iran has been undertaking maintenance activities at the EUPP.

On February 21, 2022, the IAEA "verified at [the] FMP 52 kg of uranium in the form of UO_2 powder and fuel pellets enriched up to 3.5% U-235 for KHRR." As of May 23, 2022, this value had increased to 64.4 kg of uranium in the form of UO_2 powder and fuel pellets enriched up to 3.5% U-235 for KHRR.

Part 7: Additional Protocol & JCPOA monitoring

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

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

The IAEA also reports that it cannot verify Iran's JCPOA commitments under Sections D, E, S, and T. The Section T commitments relate to prohibited nuclear weapons 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.[13]

Status of the February 2021 Agreement

Since February 2021, the IAEA has not been able to monitor Iran's production of advanced centrifuges, particularly rotors and bellows subject to JCPOA monitoring provisions, and faces a difficult challenge in reconstructing events at these sites, should Iran turn over these data. The IAEA reports, "It continues to be the Agency's understanding that surveillance data from Agency cameras installed for activities in relation to the JCPOA, as well as its on-line enrichment monitors, electronic seals or installed measurement devices, will continue to be stored and made available to the Agency if and when Iran resumes implementation of its nuclear-related commitments under the JCPOA."

[13] 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/.

On September 12, 2021, the IAEA and Iran released a joint statement providing that the "IAEA's inspectors are permitted to service the identified equipment and replace their storage media which will be kept under the joint IAEA and AEOI seals in the Islamic Republic of Iran. The way and the timing are agreed by the two sides."[14] From September 20 to 22, 2021 the IAEA serviced surveillance and monitoring equipment and replaced storage media "at all necessary locations in Iran with the exception of the centrifuge component manufacturing workshop at the TESA Karaj complex…where the agency was not provided with access."

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

Iran next sent a communication to the IAEA that was circulated to all member states reiterating its view about the TESA Karaj workshop exception, stating these monitoring commitments were not "legal obligations" and "cannot and should not be considered by the Agency as one of its entitlements." Iran also stated that its authorities were "investigating whether the terrorists [referring to the June 2021 sabotage incident via drone strike] have used the Agency cameras to launch an attack on the complex." It asked for the IAEA's cooperation "including through waiving the cameras immunity to be available for further investigation."

The Director General stated that "Iran has unilaterally interpreted the terms of the Joint Statement to exclude, ex post facto" the TESA Karaj facility and emphasized that it is "indispensable that the agreement covers all facilities and locations in Iran in order to maintain continuity of knowledge…[and] for the Agency to be in a position to resume the necessary verification and monitoring activities in Iran in relation to the JCPOA." The Director General also "categorically reject[ed] the idea that Agency cameras played a role in assisting any third party to launch an attack…" He stated that the cameras were "under continuity of knowledge" from the moment they are delivered to the IAEA and later installed. The Director General "agreed that, if Iran so requested, the Iranian authorities could inspect the cameras in the presence of Agency inspectors."

In its November 2021 report, the IAEA also concluded that the "repeated prolongation of the agreement, which has now been in place for around nine months, is becoming a significant challenge to the Agency's ability to restore...continuity of knowledge." The IAEA also stated that the absence of cameras at the TESA facility was "seriously affecting the Agency's ability to restore

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

continuity of knowledge at the workshop, which has been widely recognized as essential in relation to a return to the JCPOA."

On December 19, the IAEA "made available a sample camera and related technical information to Iran for analysis by its relevant security and judiciary officials, in the presence of the Agency inspectors." It reported that "by the end of December 2021, the Agency had reinstalled cameras to replace those removed from the workshop at Karaj and performed other related technical activities, including the replacement of all storage media in JCPOA-related cameras."

On January 19, Iran informed the IAEA of its intention to move the TESA Karaj facility to a new location in Esfahan. Although the IAEA did not identify the location, one candidate is the Esfahan tunnel complex. The Institute assesses that recent construction activities at this tunnel complex, which could house a facility deeply buried under a mountain, make it a candidate for a new centrifuge manufacturing facility.[15] The IAEA on January 22 applied seals on all production machines at the Karaj site, removed those cameras, and installed cameras "in a new workshop" at Esfahan later that month.

Subsequently, Iran changed plans. A separate IAEA report from April 14 states that on April 4, Iran moved all machines for production of centrifuge rotor tubes and bellows from the TESA Karaj site to the underground FEP at Natanz. The machines were placed under agency seals. On April 9, Iran requested the agency install surveillance cameras. On April 12, the IAEA completed the installation of cameras and removed seals from the machines for Iran's production of rotor tubes and bellows. On April 13, Iran informed the agency that it would start operating the equipment.

In its latest report, the IAEA states that "prior to the end of March 2022, the Agency replaced all of the storage media in JCPOA-related cameras." On April 12, 2022, the IAEA "completed the installation of surveillance cameras, as requested by Iran, at the Natanz site, where Iran had moved the machines for the production of centrifuge rotor tubes and bellows which were earlier located at the centrifuge component production workshop at the TESA Karaj complex."

However, the IAEA will still not have access to video recordings and data, which Iran claims it will keep in its custody until it receives relief from sanctions. The IAEA does not report whether Iran has turned over to the IAEA a missing recording unit and storage data from a camera that was destroyed at the Karaj centrifuge manufacturing facility, covering the period February until June 2021. The IAEA also 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.

[15] David Albright, Sarah Burkhard, and Spencer Faragasso, "Where Are Iran's New Centrifuge Manufacturing Capabilities?" *Institute for Science and International Security*, February 16, 2022, https://isis-online.org/isis-reports/detail/where-are-irans-new-centrifuge-manufacturing-capabilities/