INSTITUTE FOR SCIENCE AND INTERNATIONAL SECURITY

REPORT

Iranian Breakout Estimates and Enriched Uranium Stocks

By David Albright and Sarah Burkhard

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In light of a recent U.S. State Department arms control compliance report highlighting Iran's growing "uranium enrichment activities and stockpile of enriched uranium," this report presents recent Iranian breakout estimates and compares them to pivotal historical ones, where breakout is defined as the time Iran would need to produce 25 kilograms of weapon-grade uranium (WGU), enough for a nuclear weapon. As of late February 2020, the breakout estimate is 3.8 months, with a range of 3.1 to 4.6 months. This estimate is based on an Institute breakout calculator, utilizing modified ideal cascade calculations, adjusted with results from an earlier multi-year program of complex computer simulations of Iranian breakout, conducted in collaboration with centrifuge experts at the University of Virginia, and supplemented by operational data on Iranian centrifuges. The breakout estimates result from Iran's installed enrichment capacity and its stock of low enriched uranium (LEU), as reported by the International Atomic Energy Agency (IAEA) in its quarterly reports on Iran. A significant development is that Iran is at the threshold of having enough LEU to move from a four-step enrichment process to a three-step one, allowing a significant reduction of breakout times, a phenomenon referred to in the media as a "key threshold" or "enough LEU for a nuclear weapon." A potential covert enrichment plant utilizing 3000 IR-2m centrifuges is also assessed, giving a breakout of 3.1 months. The Annex to this report contains a summary of Iran's stock of low enriched uranium, based on the IAEA's most recent quarterly report on Iran, summarizing the situation as of late February 2020 and identifying which of the LEU stocks are used in the breakout calculations.

Estimated Minimal Breakout Estimates, in Months, End of February 2020

	Average	***Range***	***Trend***
Enriching at only main Natanz and Fordow plants	***3.8***	***3.1-4.6***	***decreasing***
Enriching in a clandestine plant (similar floor space as Fordow)	***3.1***	***2.7-3.9***	***potential (no evidence of secret plant)***

440 First Street NW, Suite 800, Washington, DC 20001
TEL 202.547.3633 Twitter @TheGoodISIS
E-MAIL isis@isis-online.org • www.isis-online.org

Introduction

If Iran decided to build nuclear weapons, it could use its existing, declared production-scale gas centrifuge plants, the Natanz Fuel Enrichment Plant (FEP) and the Fordow Fuel Enrichment Plant (FFEP), and low enriched uranium already produced there to make weapon-grade uranium, the key nuclear explosive material. It could also build a clandestine centrifuge plant, as it was doing in the past, where WGU could be produced without the knowledge of the International Atomic Energy Agency (IAEA) or Western intelligence.

The April 2020 U.S. State Department Compliance Report, *Adherence to and Compliance with Arms Control, Nonproliferation, and Disarmament Agreements and Commitments,* states that Iran has "progressively expanded its uranium enrichment activities and stockpile of enriched uranium, key factors in determining the amount of time required to produce enough fissile material for a nuclear weapon or device, should Iran decide to pursue nuclear weapons."[1] This time period is often referred to as the time needed to produce enough weapon-grade uranium for a nuclear weapon, or as breakout time. In line with previous conventions used by the Institute, 25 kilograms of WGU represents an amount sufficient for a single nuclear weapon.[2]

Breakout predictions are intended to represent a realistic minimum time Iran would need to produce its first 25 kilograms of WGU, alternatively referred to as a credible worst-case estimate. They account for system limitations, centrifuge breakage, and other inefficiencies, but not for all the various problems or delays of the type that have been encountered by Iran's program, which could lengthen the time needed for enrichment further.

The breakout estimate is not a "best" or average estimate of Iran's breakout, since such estimates are associated with high uncertainties, plagued by an Iranian centrifuge program in significant flux and one surrounded with great secrecy about its breakout capabilities. Just as important, calculational methodologies that emphasize simple use of "ideal cascade" calculations should be avoided, as they lead to serious underestimates of the breakout timelines and are non-plausible in the Iranian context. Similarly, not all of Iran's LEU stocks are suitable for use in a breakout, an issue discussed below and in the Annex.

It needs to be remembered that the purpose of the breakout estimate today is to measure the risk posed by Iran's increasing nuclear enrichment capabilities. As part of a risk assessment for

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[1] U.S. State Department, Bureau of Arms Control, Verification and Compliance, Executive Summary of the *2020 Adherence to and Compliance with Arms Control, Nonproliferation, and Disarmament Agreements and Commitments (Compliance Report*), April 2020, https://www.state.gov/2020-adherence-to-and-compliance-with-arms-control-nonproliferation-and-disarmament-agreements-and-commitments-compliance-report/

[2] Weapon-grade uranium is defined as uranium enriched to at least 90 percent U-235. The amount of 25 kilograms above referring to the entire amount of uranium should not be confused with what is defined as a "significant quantity" of weapon-grade uranium by the International Atomic Energy Agency (IAEA), 25 kilograms of uranium-235 in more than 90 percent enriched uranium. At 90 percent enriched, a significant quantity would correspond to 27.8 kilograms of weapon-grade uranium. Moreover, a first nuclear weapon may require more or less than 25 kilograms of WGU, depending on its design and the rate of losses in preparing weapons components from the weapon-grade uranium hexafluoride, which is the output of a centrifuge plant.

a nuclear Iran, where the risk cannot be quantified over all possibilities, including assigning probabilities to these possibilities, a realistic worst case estimate becomes a supportable way of quantifying risk, with the important proviso that a case should not be incompatible with existing knowledge about Iran's nuclear program. Likewise, cases should be avoided that arbitrarily assign difficulties to Iran achieving a breakout, given that Iran's centrifuge program can always do worse, from the point of view of lengthening breakout timelines, but it can also do better than such expectations.

Methods

Two Institute studies are relied upon in current breakout estimates:

1) *Iranian Breakout Estimates*, *Updated September 2013,* by Patrick Migliorini, David Albright, Houston Wood, and Christina Walrond,[3] October 24, 2013. https://isis-online.org/uploads/isis-reports/documents/Breakout_Study_24October2013.pdf

The Institute and experts at the School of Engineering and Applied Science at the University of Virginia (UVA) engaged in a multi-year program to quantify, via sophisticated computer simulations, Iran's ability to adapt its enrichment program to produce WGU. A range of breakout scenarios were evaluated based on the properties of IR-1 centrifuge cascades, LEU stockpiles, total installed and operating IR-1 centrifuges, and a possible covert facility containing IR-2m centrifuges. This analysis utilized a modified form of the well-known four-step enrichment process that was developed under A.Q. Khan for Pakistan's centrifuge program and transferred to other countries, such as Iran. Using all four steps, Iran would enrich natural uranium to 3.5 percent in step one, then to 20 percent in step two, 60 percent in step three, and finally to WGU in step four. The analysis also considered a subset of the four-step process with three-step and two-step processes starting with the then-existing 3.5 and near-20 percent LEU stockpiles.

2) *New Estimates of Iran's Breakout Capabilities at Declared Sites Using a New, Simple-to-Use Breakout Calculator,* by David Albright with Sarah Burkhard, September 3, 2019. https://isis-online.org/isis-reports/detail/new-estimates-of-irans-breakout-capabilities-at-declared-sites-using-a-new

This report presents a new Institute breakout calculator and its applications to several theoretical cases where Iran increases its stocks of low enriched uranium above the limits

[3] During this study, Patrick Migliorini and Professor Houston Wood were affiliated with the School of Engineering and Applied Science at the University of Virginia. An earlier study from this collaboration was William C. Witt, Christina Walrond, David Albright, and Houston Wood, "Iran's Evolving Breakout Potential," *Institute for Science and International Security*, October 8, 2012, http://isis-online.org/uploads/isis-reports/documents/Irans_Evolving_Breakout_Potential.pdf; See also, David Albright, Patrick Migliorini, Christina Walrond, and Houston Wood, "Maintaining at Least a Six-Month Breakout Timeline: Further Reducing Iran's near 20 percent Stock of LEU," *Institute for Science and International Security*, February 17, 2014, https://isis-online.org/uploads/isis-reports/documents/20_pct_stock_cap_17Feb2014-final.pdf

allowed in the Iran nuclear deal, or Joint Comprehensive Plan of Action (JCPOA). The new estimates are based on *modified ideal cascade calculations,* where the modifications are adjustments that compensate for the systematic, significant underestimating of breakout times by ideal cascade calculations applied to Iran's gas centrifuge program or other relatively small, less advanced centrifuge programs. The adjustments in the breakout calculator are based on complex computer simulations, described in reference 1) above, which model breakout times in Iran's enrichment infrastructure. The adjustments to the new calculator reflect the effect on estimated breakout in a four-step enrichment process and further inefficiencies in Iranian cascade operations, in particular that the cascades are far from ideal, as defined under ideal cascade calculations. Without these modifications to the ideal cascade calculations, these simple calculations would result in breakout times that are too short and unrealistic for Iran's centrifuge program. The net effect of these modifications to the calculator is, in general, a significant increase in predicted breakout times.

Since the finalization of the JCPOA, breakout estimates have included Iran redeploying its centrifuges that were removed from Natanz and Fordow as a result of the JCPOA. An additional consideration is whether Iran would also redeploy its 1000 IR-2m centrifuges at Natanz that were put in storage under the JCPOA as well. Both breakout cases, with or without IR-2m centrifuges, are evaluated in reference 2) above, but IR-2m redeployment early in a breakout is viewed as more likely, given that this centrifuge is one of Iran's most advanced ones and is also available to use in large numbers in a breakout. Consistent with that view, Iran redeployed an IR-2m cascade at the Natanz Pilot Fuel Enrichment Plant (PFEP) early in Iran's step-by-step violations of the JCPOA following July 1, 2019. Moreover, the IR-2m centrifuges appear to break less and operate better than the IR-1 centrifuges, which is reflected in the calculator. The calculator assumes that in this case, the 1000 IR-2m centrifuges would be reinstalled in six cascades in three months and operate better than the IR-1 centrifuges. Moreover, the IR-2m deployment would occur in parallel to the redeployment of IR-1 centrifuges that would also be installed at a rate of two cascades per month.

The calculator estimates the time to produce the first quantity of WGU. With additional centrifuge cascades added during the breakout period, Iran's enrichment capacity is greater at the end of this period than at its start. Therefore, the time to produce a second quantity of WGU would be less than the time to produce the first one, if Iran had sufficient LEU to continue with a three-step process. (Currently, Iran does not have enough LEU for two or more significant quantities of WGU produced in a three-step process.)

Breakout estimates do not include the additional time that Iran would need to convert WGU into weapons components and manufacture a nuclear weapon. This extra time could be substantial, particularly if Iran wanted to build a reliable warhead for a ballistic missile. However, these preparations would most likely be conducted at secret sites and would be difficult to detect; many relevant activities may have been ongoing for years. If Iran successfully produced enough WGU for a nuclear weapon, the ensuing weaponization process might not be detectable until Iran tested its nuclear device underground or otherwise revealed its acquisition of nuclear weapons. Therefore, the most practical strategy to prevent Iran from obtaining nuclear weapons remains preventing it from ever accumulating sufficient nuclear explosive material, particularly in secret or without adequate warning. This strategy depends on knowing how quickly Iran could make WGU.

Historical Breakout Estimates

Two breakout cases are considered first, allowing a review of earlier estimates and later permitting a comparison with current estimates. The first historical case is the time to breakout on the JCPOA's Implementation Day in January 2016, when Iran's LEU inventory was 300 kilograms, all less than 3.67 percent enriched, and it had 5060 operating IR-1 centrifuges, all at the FEP at Natanz. The breakout calculator described in reference 2) gives an estimate of 12.4 months, assuming re-deployment of only IR-1 centrifuges, the position taken by the US Department of Energy. This estimate is in line with the 12 months estimated by the U.S. government at the time. If redeployment of the IR-2m centrifuges were included, the breakout time drops to about seven to eight months. Although this period of time is still substantial, JCPOA advocates emphasized achieving a twelve-month breakout time. A more nuanced discussion was not welcomed or acknowledged publicly, despite senior Energy Department officials and later French officials revealing to one of the authors on multiple occasions this assumption of no IR-2m redeployment during a theoretical breakout.[4]

The second historical case using the calculator is a breakout estimate of 2.2 months prior to Implementation Day, when Iran had over 18,000 IR-1 centrifuges deployed and 14 tons of LEU, enriched to about 3.5 percent.[5] It should be noted that only about 1250 kilograms of 3.5 percent LEU are needed to produce 25 kilograms of WGU; Iran's LEU stock then was enough for producing 280 kilograms of WGU, representing about eleven WGU quantities. This estimate is compared to the breakout estimates of two to three months common prior to Implementation Day. An Institute study from early 2014 discusses the lengthening of breakout achieved by the 2013 Joint Plan of Action (JPA), the stepping stone to the JCPOA, estimating that the JPA lengthened breakout times from at least 1.0-1.6 months to at least 1.9-2.2 months (see Figure 1).[6]

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[4] The lack of redeployment of IR-2m centrifuges was discussed in meetings with senior Department of Energy officials and in a meeting with a political director of the French Foreign Ministry.

[5] This estimate includes a set-up time of two weeks.

[6] David Albright, Patrick Migliorini, Christina Walrond, and Houston Wood, "Maintaining at Least a Six-Month Breakout Timeline: Further Reducing Iran's near 20 percent Stock of LEU," *Institute for Science and International Security*, February 17, 2014, https://isis-online.org/uploads/isisreports/documents/20_pct_stock_cap_17Feb2014-final.pdf This estimate includes a two week set-up time.

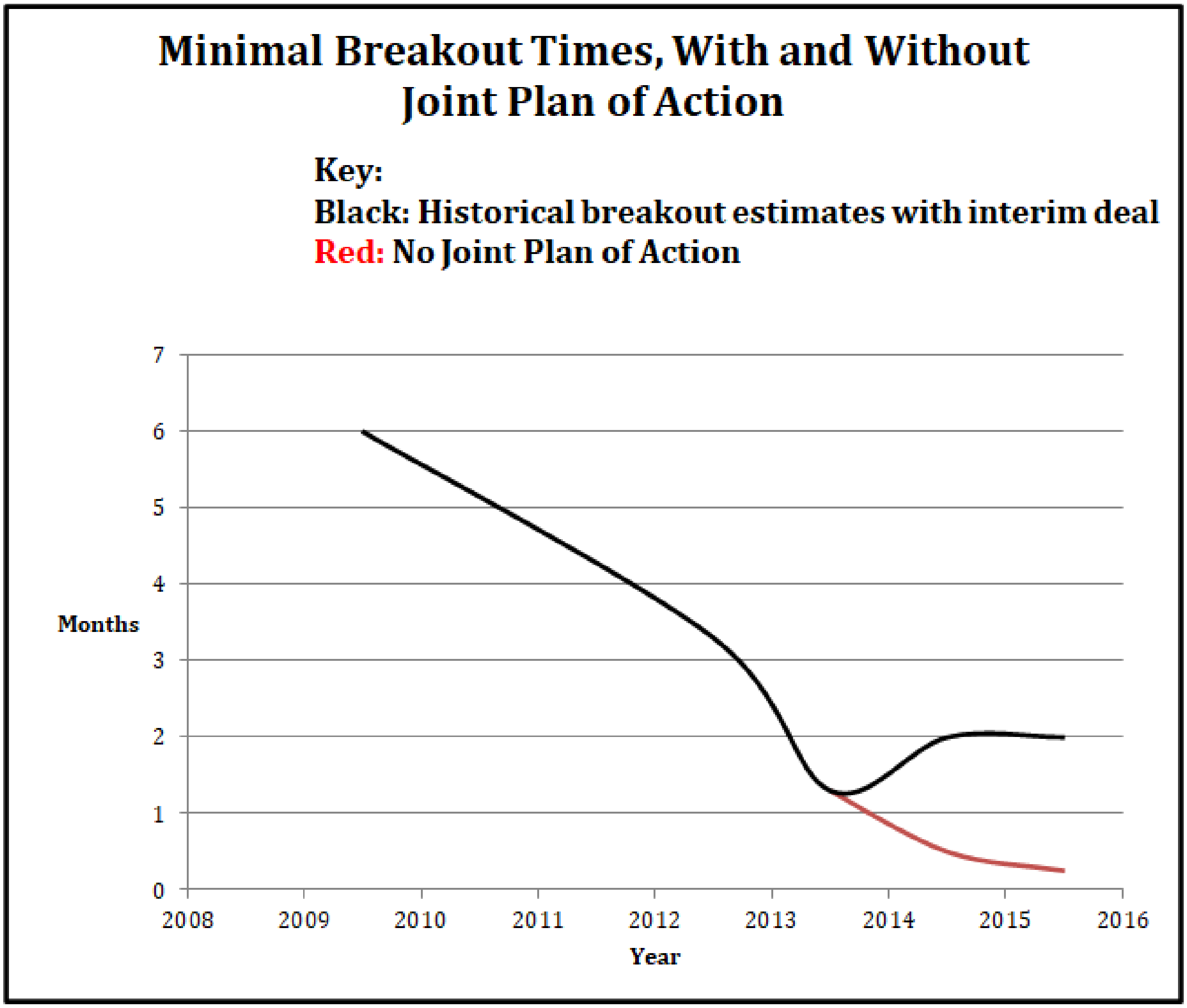

Figure 1. ISIS's estimated breakout times (central estimates) to produce enough weapon-grade uranium for a nuclear weapon in the years leading up to the JCPOA. Breakout times have gotten shorter since 2009, reaching a low near one month by the fall of 2013. Under the interim deal of the Joint Plan of Action (JPA), they increased to about two months by mid-2014. If there had been no Joint Plan of Action, breakout estimates (in red) would have shortened dangerously. Source: Institute, https://isis-online.org/isis-reports/detail/the-sixs-guiding-principles-in-negotiating-with-iran/8

Current Breakout Estimates

The breakout calculator is used to estimate current breakout times based on Iranian LEU stocks and installed enrichment capacity, using the most recent values from IAEA reporting. Table 1 below and Table A.1 in the Annex shows the stocks of LEU as of February 19, 2020.

Table 1. LEU Stocks as of late February 2020

	Uranium Mass	**Hexafluoride Mass**
Uranium enriched up to 3.67 percent*	214.6	317.5
Uranium enriched up to 4.5 percent, but >2%	537.8	795.6
Uranium enriched up to 2 percent	268.5	397.2
Totals of Enriched Uranium, less than 5%	**1020.9**	**1510.3**
Subtotal, ignoring up to 2% stocks	**752.4**	**1113.1**

*This value has shifted slightly in the last few IAEA quarterly reports. In the most recent report, the IAEA attributes the difference to further processing of some of it.

In the breakout estimate, the following conditions are assumed:

- An enrichment capacity at the Natanz and Fordow Fuel Enrichment Plants, as drawn from the latest IAEA report. The enrichment contribution from advanced centrifuges at the Pilot Fuel Enrichment Plant is not included, as their use in a breakout would be complicated and likely not contribute to reducing breakout timelines;[7]

- Only LEU stocks above two percent enriched are used. Stocks of less than two percent enriched uranium are not used, since to do so would require additional modifications of the cascades to handle the lower enrichments, likely significantly slowing or contributing only slightly, rather than speeding up breakout timelines; and

- Iran redeploys its 1000 IR-2m centrifuges, removed from the Natanz FEP prior to the JCPOA's Implementation Day; however, the rest of the centrifuges deployed are IR-1 centrifuges from Iran's existing stock. Iran may in fact deploy additional advanced centrifuges, but this effect is not included in this estimate, as none of the dozen advanced centrifuge types Iran is testing at the PFEP stands out as Iran's clear centrifuge of choice, many assessed as performing poorly.

[7] David Albright and Sarah Burkhard, "A Technical and Policy Note on Iran's Recent Announcement on its Enrichment Capacity Claims," *Institute for Science and International Security*, April 15, 2020, https://isis-online.org/isis-reports/detail/a-note-on-irans-enrichment-claims

Under these conditions, the breakout calculator gives an estimate of 3.1 months, with no initial set-up time added. Doing so would lengthen the estimate to about 3.5 months. In addition to the IR 2-m re-deployment, a major factor is that most of the LEU is already enriched to 4.5 percent instead of 3.5 percent, a significant change from estimates performed before the JCPOA's Implementation Day, since this one percent increase in enrichment can provide up to a 15 to 20 percent reduction in breakout time to produce 25 kilograms of weapon-grade uranium. The greater enrichment level also means that the production of 25 kilograms of weapon grade uranium requires less LEU than if it were enriched to 3.5 percent: 900 kilograms of 4.5 percent LEU vs. 1250 kilograms of 3.5 LEU. This last condition is particularly significant here, since it means that the existing amount of LEU is enough to reach the requisite amount of weapon-grade uranium without the need to also use some natural uranium to make a portion of the needed WGU. As a result, the process is strictly a three-step one instead of a three-step followed by a four-step one. This ability to use only three steps to reach weapon-grade, instead of four, is why the media often discusses a key threshold of about 1000 kg of LEU as significant.[8]

As discussed in the Annex, it is possible that the average enrichment level is lower than assumed above. If the enriched uranium in these two stocks is assumed to have an average uniform enrichment level of 3.5 percent instead of 4.5 percent, then the breakout estimate is 4.6 months. In this estimate, a set-up and/or transition time of about two-thirds of a month is assumed, when no enrichment is taking place. Another reason for the longer breakout increase is that a stock of 1113 kilograms of 3.5 percent LEU is not enough by itself to produce 25 kilograms of WGU, requiring the feeding of some natural uranium in a four-step instead of a three-step process. If there were enough LEU, e.g. 1250 kg, the breakout time would reduce to 3.5 months, assuming no initial set-up time.

If the average of the range of 3.1 to 4.6 months is used, the estimated breakout time as of late February 2020 is 3.8 months, but decreasing.

Breakout in a Potential Covert IR-2m Enrichment Facility

An earlier Institute study, using documents from the Iran Nuclear Archive and IAEA inspector observations, demonstrated that the Fordow enrichment plant was originally designed as a plant to make weapon-grade uranium from LEU.[9] At the time, the principal centrifuge was the IR-1 centrifuge. This breakout case considers a covert enrichment plant of similar size, holding 3000 IR-2m centrifuges, using LEU produced elsewhere as feedstock to enable a faster breakout in a three-step enrichment process to reach weapon grade, where the only LEU is enriched below five percent. This case is partially motivated by lingering uncertainty surrounding Iran's past production of IR-2m centrifuges. While six cascades holding 1008 IR-2m centrifuges

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[8] David E. Sanger and William J. Broad, "Iran Crosses a Key Threshold: It Again Has Sufficient Fuel for a Bomb," *The New York Times*, March 3, 2020, https://www.nytimes.com/2020/03/03/world/middleeast/iran-nuclear-weapon-trump.html

[9] David Albright, Frank Pabian, and Andrea Stricker, "The Fordow Enrichment Plant, aka Al Ghadir," *Institute for Science and International Security,* March 13, 2019, https://isis-online.org/isis-reports/detail/the-fordow-enrichment-plant-aka-al-ghadir

installed at the FEP were removed and put in storage under the JCPOA, the unit had been set up to hold an additional 12 cascades, for a total of 18 cascades of IR-2m centrifuges. On August 24, 2013, the IAEA reported that "preparatory installation work had been completed for the other 12 IR-2m cascades in the unit."[10] It appears illogical that Iran would have halted production of IR-2m centrifuge while preparing the FEP for new installations. Yet, up until this day, it remains unknown how many of the planned 3000 IR-2m centrifuges were produced, fully or partially, a critical question the JCPOA did not answer before or after it was implemented; neither has the IAEA answered it.

Reference 1): This scenario was considered in the 2013 study, where each IR-2m was assigned a possible enrichment output of either three or five separative work units per year (swu/year) and the LEU enrichment level was 3.5 percent, the maximum level of LEU enriched less than five percent at the time. Knowledge about the IR-2m centrifuge was lacking in 2013, when this study was written; a broad range was selected to include all possibilities. In the case of the three-step process, the breakout estimate is 2.2 and 4.5 months, where the former reflects a five swu/year machine and the latter, a three swu/year machine.[11] In this study, Iran possessed more than enough LEU to meet the threshold of using a three-step process.

Breakout calculator: The breakout calculator assigns each IR-2m a value of about 3.6 swu/year based on IAEA data of IR-2m centrifuges operating in a cascade of 164 centrifuges. This case considers a range defined by enrichment levels, namely 3.5 and 4.5 percent enriched uranium, where each subcase assumes enough LEU to meet the three-step threshold. The breakout result is 2.7 and 3.1 months, where the former corresponds to 4.5 percent enriched and the latter, 3.5 percent enriched.[12]

In order to compare the two sets of results, it is helpful to scale the breakout results of 2.2 and 4.5 months from reference 1) to a breakout estimate with the enrichment output of the IR-2m used by the breakout calculator, namely 3.6 swu/year, arriving at a corresponding breakout estimate of 3.81 months. This value compares to the breakout time of 3.1 months from the calculator. Their average is 3.46 months.

Because the average enrichment level of the LEU is not currently known precisely—but taken as either 3.5 or 4.5 percent, the average of these two scenarios is used. In this case, the values of 3.46 and 2.7 months are averaged, resulting in 3.08 months, or rounded to 3.1 months. The range is assigned as 2.7 to 3.9 months.

Alternatively, taking an average of all four breakout estimates (2.2, 2.7, 3.1, and 4.5 months) independently gives a value of 3.12 months, rounded to 3.1 months.

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[10] IAEA Director General, *Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions in the Islamic Republic of Iran,* GOV/2013/40, August 28, 2013, https://www.iaea.org/sites/default/files/gov2013-40.pdf

[11] This estimate includes a set-up time of two weeks.

[12] This estimate includes a set-up time of two weeks.

Annex on LEU stock at end of last reporting quarter of the IAEA, based on March 3, 2020 report on Iran[13]

Low Enriched Uranium

The IAEA disclosed in its last quarterly report that Iran has continued to exceed the JCPOA's cap of 300 kilograms (kg) of low enriched uranium (hexafluoride mass), or 202.8 kg (uranium mass). On July 1, 2019, the IAEA first reported that Iran had surpassed the JCPOA's LEU stock limit by enriching 205.0 kg of LEU (uranium mass).[14] Iran also continued to enrich up to 4.5 percent, in violation of the 3.67 percent enrichment limit under the deal. The IAEA first stated on July 8, 2019, that Iran was enriching up to a level of 4.5 percent.[15]

On February 19, 2020, the IAEA's most recent public verification date, Iran possessed a stockpile of about 1510 kg of low enriched uranium (hexafluoride mass), all enriched below five percent, or the equivalent of 1020.9 (uranium mass). In terms of uranium mass, this stock increased by 648.6 kg since the last IAEA quarterly report; in terms of hexafluoride mass, the increase was 959 kg.

The additional stocks of enriched uranium reported in this IAEA report were produced at the Natanz Fuel Enrichment Plant (FEP), Fordow Fuel Enrichment Plant (FFEP), and the Pilot Fuel Enrichment Plant (PFEP).

This LEU stock is composed of three bins, characterized by dates of production and enrichment level. The first bin is enriched uranium enriched up to 3.67 percent and produced prior to July 8, 2019, totaling 214.6 kg (uranium mass) or 317.5 kg (hexafluoride mass). The second bin is uranium enriched up to 4.5 percent but above 2 percent and produced after July 8, 2029, totaling 537.8 kg (uranium mass) and 795.6 kg (hexafluoride mass). The third bin holds uranium enriched up to 2 percent and produced after July 8, 2019, totaling 268.5 kg (uranium mass) or 397.2 kg (hexafluoride mass). The enriched uranium in the third bin stems from advanced centrifuges in lines 2 and 3 at the Pilot Fuel Enrichment Plant.[16] These values, and ones from earlier reporting periods, are listed in Table A.1.

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[13] IAEA Director General, *Verification and monitoring in the Islamic Republic of Iran in light of United Nations Security Council resolution 2231 (2015),* GOV/2020/5, March 3, 2020, https://isis-online.org/uploads/iaea-reports/documents/IAEA_quarterly_Iran_report_February_2020.pdf

[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/2019/8, July 1, 2019, https://www.iaea.org/sites/default/files/19/07/govinf2019-8.pdf

[15] IAEA Director General, *Verification and monitoring in the Islamic Republic of Iran in light of United Nations Security Council resolution 2231 (2015),* GOV/INF/2019/9*,* July 8, 2019, https://www.iaea.org/sites/default/files/19/07/govinf2019-9.pdf

[16] David Albright and Sarah Burkhard, "A Technical and Policy Note on Iran's Recent Uranium Enrichment Capacity Claims," *Institute for Science and International Security,* April 15, 2020, https://isis-online.org/isis-reports/detail/a-note-on-irans-enrichment-claims

Table A.1. Enriched Uranium Quantities, less than 5 percent, all quantities in uranium mass only (kg)*

	5/2019	8/2019	11/2019	2/2020
Chemical Form				
UF_6	153.2	218.9	349.9	996.5
Uranium oxides and their intermediate products	10.4	11.1	10.4	9.7
Uranium in fuel assemblies and rods	4.3	4.6	4.6	7.7
Uranium in liquid and solid scrap	6.2	7.0	7.4	7.0
Enrichment Level Subtotals				
Uranium enriched to 3.67 percent**	174.1	216.5	212.6	214.6
Uranium enriched to 4.5 percent but >2%	0	25.1	129.2	537.8
Uranium enriched to 2 percent	0	0	30.5	268.5
Totals of Enriched Uranium, <5%	**174.1 kg**	**241.6 kg**	**372.3 kg**	**1020.9**

*These totals do not include undisclosed stocks of enriched uranium exempted by the Joint Commission.
**This value has shifted slightly in the last few IAEA quarterly reports. In the most recent report, the IAEA attributes the difference to further processing of some of it. The reason for the discrepancy from August to November 2019 was not explained.

In Table A.1, the May vs. August vs. November 2019 vs. February 2020 comparisons show how Iran has increased its stockpile of LEU hexafluoride, as measured in uranium mass. The enriched uranium bin containing between 2 and 4.5 percent enriched uranium was produced mostly in the Fordow and Natanz enrichment plants. The amount produced in each plant is not provided. Likewise, it is not known how much, if any, enriched uranium from lines 4, 5, and 6 in the PFEP are included in this bin.[17] The enrichment level of that uranium may be significantly less than 4.5 percent although still above 2 percent. Nonetheless, in the absence of contrary information, the bulk of the enriched uranium in this bin is assumed to be near 4.5 percent.

In terms of calculating monthly averages, the most significant bin is the one with between 2 and 4.5 percent enriched uranium, where its stock increased by 408.6 kg (uranium mass) during the last reporting period, which ran from November 3, 2019 until February 19, 2020, a total of 108 days. During this period, the monthly average was 114 kg per month (uranium mass), or 168 kg per month (hexafluoride mass).

In the previous reporting period, covering August 19 to November 3, 2019, the average rate was about 51.6 kg per month of enriched uranium (uranium mass) and 76.3 kg per month of enriched uranium (hexafluoride mass). In this reporting period, compared to the previous one, average monthly enriched uranium production more than doubled. Using a simple, ideal cascade enrichment calculator, where all the enriched uranium is assumed to be at 4.5 percent,

[17] Ibid.

this monthly rate corresponds to the enrichment output of about 600 swu per month, somewhat higher than expected to be produced only in the FEP and FFEP, which currently host centrifuge cascades capable of about 400 swu per month. Given that likely more separative work was needed to make this enriched uranium, it is possible that a significant amount of the enriched uranium in this bin is not at the level of 4.5 percent or some may be from lines 4, 5, and 6 from the PFEP. A breakdown of the enrichment levels and origins of the “up to” 4.5 percent LEU bin in the next quarterly IAEA report would provide clarity.

Another question, albeit speculative at this time, involves the possibility that increased production of LEU at the FEP and FFEP resulted from inadvertent assistance Iran may have received from Russia under the JCPOA on stable isotope separation in IR-1 centrifuges. This assistance may have unintentionally allowed Iran to significantly increase the separative output of the IR-1 centrifuge cascades, now enabling Iran to run its IR-1 centrifuges noticeably more efficiently than before.

The stock of less than 2 percent LEU also saw a significant increase in this reporting period, from 30.5 to 268.5 kg values (uranium mass). However, without knowing its enrichment level, one is hard pressed to judge its significance, since the amount of enrichment effort, or separative work, to make enriched uranium at such low levels, varies tremendously. Moreover, this stock of LEU is not used in our breakout estimates, since it would require special modifications of the cascades to handle it, likely slowing or contributing only slightly, rather than speeding up breakout significantly.