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Iran's Uranium Enrichment Program: June 2021 Update

One of the most worrisome aspects of centrifuge enrichment plants is that even if they are configured to produce only low enriched uranium, they can easily be used to produce the highly enriched uranium (HEU) required for nuclear weapons using a batch recycling process. In a prior paper, I described how Iran could carry out this process in its current centrifuge enrichment facilities by sending the low enriched uranium that it is currently producing[2] back through the cascade three more times.[3] (See Appendix) This batch recycling would produce the intermediate products of 20% and 60% enriched uranium before producing 90% enriched uranium for nuclear weapons. Only minor modifications to the centrifuge plant are needed to carry out this process.

Information provided by the International Atomic Energy Agency's (IAEA) safeguards updates in February 2021 and May 2021, demonstrate that Iran has made significant advances towards producing 90% enriched uranium for nuclear weapons.[4] Iran has continued producing low enriched uranium and now has sufficient material to produce two nuclear weapons, each of which would contain the 20 kilograms of 90% enriched uranium needed to produce a nominal yield nuclear weapon (in the 10 to 20 kiloton range).

In addition, since January 4, 2021, Iran has been producing 20% enriched uranium and on April 17, 2021 Iran began producing 60% enriched uranium. Iran has also started deploying significant numbers of advanced centrifuges. They have an enrichment capacity of approximately three times that of Iran's current centrifuges, so that even just a few of these cascades significantly increases Iran's enrichment capacity. These steps by themselves would shorten the time required for Iran to produced 90% enriched uranium.

On the other hand, on April 11, 2021, an attack (physical explosive or cyber) damaged the power supply at Iran's main enrichment site at Natanz. This resulted in the damage or destruction of about half of the centrifuge cascades at this site. This loss would tend to hinder Iran's ability to quickly produce 90% enriched uranium.

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[1] This paper is the product of the author's personal research and the analysis and views contained in it are solely his responsibility. Though the author is also a part-time adjunct staff member at the RAND Corporation, this paper is not related to any RAND project and therefore RAND should not be mentioned in relation to this paper. I can be reached at GregJones@proliferationmatters.com

[2] The IAEA describes this material as being enriched "up to 5%."

[3] Gregory S. Jones, "Iran's Uranium Enrichment Program Making Strides but Still At Least Six Months From Being Able to Produce Enough HEU for a Nuclear Weapon." April 2, 2020. https://nebula.wsimg.com/0110bd8db6cebe189303e8aa10b23ece?AccessKeyId=40C80D0B51471CD86975&disposition=0&alloworigin=1

[4] Verification and monitoring in the Islamic Republic of Iran in light of United Nations Security Council resolution 2231 (2015)," GOV/2021/10, International Atomic Energy Agency, February 23, 2021 https://www.iaea.org/sites/default/files/21/03/gov2021-10.pdf and Verification and monitoring in the Islamic Republic of Iran in light of United Nations Security Council resolution 2231 (2015)," GOV/2021/28, International Atomic Energy Agency, May 31, 2021. https://www.iaea.org/sites/default/files/21/06/gov2021-28.pdf

The net result of these developments is that Iran could produce a nuclear weapon's worth of HEU in just two months from today if it chose to do so. (See detailed analysis in Appendix) It could produce enough HEU for a second weapon in an additional two months. This latter time interval is somewhat uncertain since it depends on how quickly Iran continues deploying advanced centrifuges and whether Iran can repair any of the damaged centrifuges at Natanz. After producing two nuclear weapons, Iran will have exhausted its stocks of low enriched uranium and it could take six months to a year for Iran to produce sufficient HEU for a third nuclear weapon.

What is to be done to stop Iran's steady progress towards an eventual nuclear weapon? There appears to be no satisfactory solution. Covert action is being taken against Iran's nuclear weapon program. In July 2020, an explosion and fire destroyed the Iran Centrifuge Assembly Center near Natanz. On November 27, 2020, a key Iranian scientist, Mohsen Fakhizadeh, was assassinated. On April 11, 2021 an attack on Iran's main enrichment facility at Natanz disabled or destroyed nearly half of the centrifuges there. These actions, while slowing Iran's progress, are insufficient to stop its nuclear weapon program as illustrated by the short time required for Iran to produce sufficient HEU for a nuclear weapon.

I feel that the current U.S. policy of maximum pressure is the best one available, as it has imposed serious economic costs on Iran which, if nothing else, may deter other countries from following in Iran's footsteps. However, it appears that Iran is so determined to acquire nuclear weapons that it is willing bear these costs to achieve its goal.

President Biden is attempting to revive the Iran nuclear deal, formally known as the Joint Comprehensive Plan of Action (JCPOA). One of the main problems with this suggestion is that by July 2021, five and a half years of this agreement will have already elapsed. In two and a half years, in January 2024, some of the restrictions on Iran's centrifuge manufacturing and testing expire. In four and a half years, that is in January 2026, there will no longer be any restrictions on the number or types of centrifuges that Iran is allowed to deploy. Once Iran is operating a large number of advanced centrifuges, the time required for Iran to produce HEU for nuclear weapons would become quite short, as President Obama admitted in 2015.[5] Further, returning to the JCPOA would also remove the severe economic costs imposed by the maximum pressure sanctions, restoring Iran's economy and easing its path to a nuclear weapon.

Given this poor outlook for stopping Iran's acquisition of nuclear weapons, a military strike on Iran's centrifuge enrichment facilities has sometimes been suggested. However, I am opposed to such action since a single military strike will do little to slow Iran's progress towards nuclear weapons and sustained military action would probably lead to a major war with Iran.[6]

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[5] He said "…at that point the breakout times would have shrunk almost down to zero." See: "Transcript: President Obama's Full NPR Interview On Iran Nuclear Deal," April 7, 2015. https://www.npr.org/2015/04/07/397933577/transcript-president-obamas-full-npr-interview-on-iran-nuclear-deal

[6] See my prior analysis of this issue: Gregory S. Jones, "Iran's Uranium Enrichment Program: November 2020 Update," December 7, 2020, pp. 3-4. https://nebula.wsimg.com/58abfdb174612aafa1d84d8b208e4233?AccessKeyId=40C80D0B51471CD86975&disposition=0&alloworigin=1

In sum, Iran's appears to be determined to use its supposedly peaceful nuclear facilities to acquire nuclear weapons, despite the heavy economic costs imposed by U.S. sanctions. On June 28, 2021, President Biden pledged that "Iran will never get a nuclear weapon on my watch." It is not at all clear how he will be able to make good on this pledge.

Appendix

Detailed Analysis of the IAEA February 23, 2021, and May 31, 2021, Safeguards Reports and Methods Whereby Iran Could Produce HEU for Nuclear Weapons

The JCPOA allowed Iran to retain six cascades (1,044 IR-1 centrifuges) at the Fordow Fuel Enrichment Plant (FFEP), though they were not allowed to enrich uranium. Between November 2019 and January 2020, these six cascades began to enrich natural uranium to uranium enriched up to 4.5%. At the beginning of 2021, these cascades were reconfigured as three sets of two tandem cascades and since January 4, 2021, they have been producing up to 20% enriched uranium. The IAEA has stated that initially Iran used 4.1% enriched uranium as feed.[7] Iran used the two tandem cascade arrangement before the JCPOA was negotiated to produce 19.7% enriched uranium. In this earlier case the tails were 0.711% enriched (i.e. the enrichment of natural uranium) and one can assume that similar tails are now being produced at the FFEP.

The latest IAEA safeguards report stated that between February 16 and May 21, 2021, Iran produced 41.2 kilograms of uranium enriched up to 20% at the FFEP.[8] This is a production rate of 13.3 kilograms a month.[9] The IAEA stated that the feed was 258.5 kilograms of uranium enriched up to 5%. This is a feed rate of 83.7 kilograms per month.

Using a separative work calculator, and assuming a product enrichment of 20%, a tails enrichment of 0.711% and a feed enrichment of 4.1%, the production of 41.2 kilograms of product would require only 234.5 kilograms of feed, instead of the 258.5 reported. To make the numbers approximately match, the feed would need an enrichment of only 3.8%. It is not clear why the feed enrichment would be so low and opens up the possibility that Iran could increase its rate of production of 20% enriched uranium in the future by using feed with a higher enrichment.

In response to the attack on Iran's main enrichment plant, the Fuel Enrichment Plant (FEP) at Natanz, on April 11, 2021, Iran began using various R&D cascades at the Pilot Fuel Enrichment Plant (PFEP), to produce 60% enriched uranium on April 17, 2021. The PFEP was not affected by the attack on the FEP (nor was the FFEP). Given the short time interval between the attack and the start of 60% enriched uranium production, Iran did not have much time to prepare and the method first used was apparently not optimal. In the latter part of April, Iran twice changed its method for producing 60% enriched uranium.

Since May 3, 2021, Iran seems to have hit upon a very effective way to produce 60% enriched uranium. This method appears to reduce the amount of feed required and allows for the production some 20% enriched uranium as well. The overall tails have an enrichment of about

[7] Verification and monitoring in the Islamic Republic of Iran in light of United Nations Security Council resolution 2231 (2015)," GOV/2021/2, International Atomic Energy Agency, January 4, 2021, p. 1. https://www.iaea.org/sites/default/files/21/03/govinf2021-2.pdf

[8] The IAEA reports this number in terms of uranium hexafluoride mass. In all cases in this paper, just the uranium mass is used with the mass of the fluoride removed.

[9] To avoid the problem that months have different numbers of days, a uniform month of 30.44 days is used though out this paper.

that of natural uranium so that they can be used at the FEP to produce more enriched uranium. According to the IAEA, Iran feeds a cascade of IR-6 centrifuges in line 6 at the PFEP with uranium enriched up to 5% and produces 60% enriched uranium product. The tails from line 6 are fed into a cascade of IR-4 centrifuges in line 4. This cascade produces 20% enriched uranium. Its tails are fed into a cascade composed of both IR-5 and IR-6 centrifuges in line 1. The product is uranium enriched up to 5% and the tails that are approximately the concentration of natural uranium.

Note the IAEA did not provide the exact enrichment of the uranium feed to line 6, nor did it provide the amount and enrichment of the tails produced by line 6 and line 4. However, assuming that the feed to line 6 and the product from line 1 have the same enrichment, and assuming that the product of line 6 and line 4 are exactly 60% and 20% enriched uranium respectively, it is possible to work out all of the parameters for 60% enriched uranium production at the PFEP between May 3 and May 21. The results are shown in table 1.

Table 1

Production Method for 60% Enriched Uranium at the PFEP
Data for the Interval May 3 to May 21, 2021

Centrifuge Type and Production Line	Product Enrichment and Quantity	Feed Enrichment and Quantity	Tails Enrichment and Quantity
IR-6, Line 6	60% 1.1 kg	3.63% 39 kg	2.0% 37.9 kg
IR-4, Line 4	20% 1.6 kg	2.0% 37.9 kg	1.2% 36.3 kg
IR-5/IR-6, Line 1	3.63% 6.1 kg	1.2% 36.3 kg	0.711% 30.2 kg
Net Total	60% & 20% 1.1kg & 1.6 kg	3.63% 32.9 kg	0.711% 30.2 kg

As can be seen for this 18 day interval, a net of 32.9 kilograms of uranium enriched to 3.63% was used as feed and the products were 1.1 kilograms of 60% enriched uranium and 1.6 kilograms of 20% enriched uranium. The tails were 30.2 kilograms of uranium with an enrichment equivalent to natural uranium which could be used as feed in the FEP. Given the efficiency of this setup, I will assume that this will be the production procedure at the PFEP for the near future.

On a monthly basis, the data in Table 1 totals up to the production of 1.9 kilograms of 60% enriched uranium, 2.7 kilograms of 20% enriched uranium with the consumption of 55.6 kilograms of 3.63% enriched uranium. It is surprising that by using only a single cascade in line 6, Iran is able to increase the enrichment from 3.63% enriched to 60% enriched. If this cascade were to be fed 20% enriched uranium, then it would directly produce the 90% enriched uranium desired for nuclear weapons. It is also surprising that the feed is only 3.63% enriched, which is lower than the 3.7% enrichment allowed by the JCPOA. Iran may be using some of the 202 kilograms of 3.7% enriched uranium that it had stockpiled before it began enriching to higher levels in 2019, though at current rates of consumption, this stockpile will only last for about four months. Using higher enriched feed in line 6, Iran could either produce a product with an enrichment higher that 60% or increase its rate of 60% enriched uranium production.

The 2.7 kilograms of 20% enriched uranium being produced per month at the PFEP when added to the production at the FFEP, means that Iran is producing 16.0 kilograms of 20% enriched uranium per month. The consumption of uranium feed enriched up to 5% at both the PFEP and FFEP totals about 139 kilograms per month. This amount is likely more than the current production of uranium with an enrichment of up to than 5% at the FEP. As a result, Iran is probably starting to draw down its stocks of this material. Whether this draw down will continue will depend on how quickly Iran can increase production at the FEP by deploying additional advanced centrifuges or repairing the cascades damaged in the April 11, 2021 attack.

It is also possible to calculate the separative work (SWU) output per centrifuge of the advanced centrifuges at the PFEP using the data in Table 1. The IR-6 centrifuges have an output of 2.9 SWU/yr, the IR-4s 2.5 SWU/yr and the IR-5s 3.6 SWU/yr. It is possible that by using the cascades in lines 6 and 4 to produce a large span of enrichment (from 3.63% to 60% in line 6 and from 2.0% to 20% in line 4), the operation of the centrifuges has been adjusted in such a way that the annual SWU production is reduced. For my analysis here, I will make the simplifying assumption that all of Iran’s advanced centrifuges have an annual output of 3 SWU/yr. This is about three times the output of Iran’s most common centrifuge, the IR-1.

The current situation at the FEP is hard to determine due to the attack on April 11, 2021. Iran has installed 30 cascades of IR-1s, 6 cascades of IR-2ms, and 2 cascades of IR-4s at the FEP. However, apparently due to the April attack, only 15 cascades of IR-1s, 3 cascades of IR-2ms and 2 cascades of IR-4s were actually enriching uranium on May 24. It is not known how seriously damaged the other 18 cascades (15 IR-1s and 3 IR-2ms) are but for my analysis I will assume that they are not returned to service. Iran also has informed the IAEA that it plans to install 6 additional IR-1 cascades, 4 IR-4 cascades and 1 IR-6 cascade at the FEP. I will assume that for my breakout calculations, these additional cascades do not enter service in the next few months. Given the cascades that are in operation at the FEP, I estimate its current enrichment output is about 5,200 SWU/yr.

My Iran breakout calculations assume that Iran starts producing the HEU required for a nuclear weapon at the beginning of July 2021. I assume that Iran’s goal is to produce 20 kilograms of 90% enriched uranium using the centrifuges at the FEP. According to the IAEA, as of May 21, 2021, Iran had 1,773.2 kilograms of uranium enriched up to 5%, 62.8 kilograms of uranium enriched up to 20% and 2.4 kilograms of uranium enriched up to 60%. Since production has continued, I estimate that at the end of June Iran had about 1,700 kilograms of uranium enriched up to 5%, about 80 kilograms of uranium enriched up to 20% and about 4 kilograms enriched up to 60%. Since production will continue at the FFEP and the PFEP while the breakout is occurring, I estimate that in total Iran will have about 95 kilograms of uranium enriched up to 20% and 6 kilograms of uranium enriched up to 60% for a July 2021 breakout. For my calculations I assume that uranium enriched up to 5% is 4.5% enriched, uranium enriched up to 20% is 19.7% enriched and uranium that is enriched up to 60% is 60% enriched.

I assume that at the FEP, in their standard mode of operation, the cascades enrich natural uranium to 4.5% enriched uranium, producing tails with an enrichment of 0.31%. The FEP could produce 90% enriched uranium most expeditiously by using batch recycling where the 4.5% enriched uranium is sent back though the cascades three more times. In the first pass, the enrichment is increased to 19.7%, the second 60% and the third 90%.[10] Assuming a setup time for each pass of 2 days, the production of 20 kilograms of 90% enriched uranium would take Iran about 50 days (about 7 weeks). The calculations are shown in Table 2.

Table 2

Time, Product and Feed Requirements for Iran to Produce 20 kg of HEU for Its First Weapon by Batch Recycling at the FEP (Enrichment Capacity 5,200 SWU per year)

Cycle	Product Enrichment and Quantity	Feed Enrichment and Quantity	Tails Enrichment and Quantity	Time for Cycle (Days)
First	19.7% 120 kg	4.5% 850 kg	2.0% 730 kg	33
Second	60% 43.1 kg	19.7% 215 kg*	9.6% 172 kg	9
Third	90% 20 kg	60% 49.1 kg**	39.4% 29.1 kg	2
Total				50***

* 95 kg of 19.7% enriched uranium provided by the FFEP and PFEP.
** 6 kg of 60% enriched uranium provided by the PFEP.
*** Includes six days to account for equilibrium and cascade fill time.

As can been seen in Table 2, the FEP would consume 850 kilograms of 4.5% enriched uranium. The continued operation of the FFEP and PFEP for another month would consume 139 kilograms of 4.5% enriched uranium, so that Iran would have about 700 kilograms of 4.5% enriched uranium from its stockpile left after having produced the HEU for its first nuclear weapon. However, Iran could use natural uranium to dilute the tails from the third cycle in Table 2 to produce about 59 kilograms of 19.7% enrich uranium and dilute the tails from the second cycle to produce about 400 kilograms of 4.5% enriched uranium.[11] Further, during the production of the HEU for its second weapon, Iran could produce an additional 2 kilograms of 60% enriched uranium at the PFEF and 16 kilograms of 19.7% enriched uranium at the FFEP and PFEP. Therefore, for Iran to produce its second 20 kilograms of 90% enriched uranium, Iran

[10] The tails are 2.0%, 9.6% and 39.4% respectively.
[11] Iran could also use enrichment tails produced by the normal operation of the FEP to dilute the 2.0% enriched uranium tails produced by the first cycle to the concentration of natural uranium. Though this step would improve its management of its natural uranium resources, it will not increase the speed of Iran's breakout.

would have available about 2 kilograms of 60% enriched uranium, 75 kilograms of 19.7% enriched uranium and 1,100 kilograms of 4.5% enriched uranium.

Assuming that the FEP's enrichment output is still only 5,200 SWU per year, then it would take Iran about an additional 2 months to produce the HEU for its second nuclear weapon. My calculations are shown it Table 3. These calculations are probably conservative, since by the latter part of this year the FEP will likely have an enrichment output significantly higher than 5,200 SWU/yr.

After having produced the HEU for its second nuclear weapon, Iran would have exhausted its stockpile of 4.5% enriched uranium. It could take Iran another six months to a year before it could replenish its stocks of 4.5% enriched uranium and be able to produce an additional 20 kilograms of 90% enriched uranium for a third nuclear weapon.

Table 3

Time, Product and Feed Requirements for Iran to Produce 20 kg of HEU for Its Second Weapon by Batch Recycling at the FEP (Enrichment Capacity 5,200 SWU per year)

Cycle	Product Enrichment and Quantity	Feed Enrichment and Quantity	Tails Enrichment and Quantity	Time for Cycle (Days)
First	19.7% 160 kg	4.5% 1,130 kg	2.0% 970 kg	44
Second	60% 47.1 kg	19.7% 235 kg*	9.6% 188 kg	10
Third	90% 20 kg	60% 49.1 kg**	39.4% 29.1 kg	2
Total				62***

* 75 kg of 19.7% enriched uranium provided by tails dilution and the FFEP and PFEP.
** 2 kg of 60% enriched uranium provided by the PFEP.
*** Includes six days to account for equilibrium and cascade fill time.