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IRAN'S EVOLVING BREAKOUT POTENTIAL

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EXECUTIVE SUMMARY

If Iran decided to build nuclear weapons, it could use its existing safeguarded nuclear facilities and nuclear materials to produce weapon-grade uranium (WGU, uranium enriched to 90 percent U-235). This report evaluates scenarios, commonly called "breakout" or "dash" scenarios, by which Iran could produce enough WGU for one or more nuclear weapons. The authors use one significant quantity (SQ), defined as 25 kilograms of WGU, to represent the amount of WGU needed for a nuclear weapon.

The report estimates minimum breakout times given Iran's capabilities as of the August 2012 International Atomic Energy Agency (IAEA) Safeguards Report on Iran and given its expected future capabilities when it may have a much larger stock of near 20 percent low enriched uranium (LEU). The authors utilize computer simulations which model Iran's enrichment infrastructure, accounting for performance limitations specific to its first generation IR-1 centrifuges and their arrangement into cascades. The breakout scenarios involve the Natanz Fuel Enrichment Plant and the Fordow Fuel Enrichment Plant, Iran's two production-scale declared gas centrifuge plants.

Predictions are given for the time needed to enrich one SQ of WGU; the estimates do not include the time necessary for the nuclear weaponization process. If Iran were to attempt to make a nuclear weapon, it would likely face new engineering challenges, despite work it may have done in the past. Iran would thus need many additional months to manufacture a nuclear device suitable for underground testing and even longer to make a reliable warhead for a ballistic missile.

Limited knowledge of the specifics of Iran's enrichment program complicates efforts to predict its centrifuge performance in a breakout scenario. Accordingly, the predictions are often given in range format, where the range itself is intended to be a best estimate, not an absolute minimum or maximum. The estimates are intended to represent the minimum time Iran would require to produce one significant quantity of WGU. Various problems or delays of the type often encountered by Iran's program could lengthen the necessary enriching time.

Currently, ISIS assesses that Iran would require at least 2-4 months to produce one SQ of WGU at the Natanz Fuel Enrichment Plant and would need to utilize its stocks of 3.5 and near 20 percent LEU. The quickest estimates are 2 to 2.3 months, and they rely on an amount of near 20 percent LEU hexafluoride that was scheduled for conversion to another form as of August 2012. Growth in the stock of near 20 percent LEU reduces the time needed to break out, even though this stock is not currently large enough on its own to produce one SQ.

These minimum breakout times assume Iran would aim to produce only one SQ of WGU. The simulations show that producing one SQ as fast as possible would use up a considerable amount of Iran's stored 3.5 and near 20 percent LEU. If Iran wanted multiple SQs it could use its LEU more judiciously, but as a consequence it would require more time for the first SQ. With its August 2012 stockpiles, ISIS estimates that Iran could make relatively quickly only two SQs of WGU using the Fuel Enrichment Plant with its currently configured single cascades. It could

produce those two SQs in a minimum of 4.6-8.3 months. Afterwards, Iran would have enriched uranium leftover from the process that it could recycle to make more WGU, but the next SQ would take longer to produce than each of the first two. If the cascades were reorganized into tandem pairs at the Natanz Fuel Enrichment Plant, Iran could make two SQs somewhat faster – in 3.9-6.9 months – and would retain enough stored LEU to make two additional SQs, for a total of four, using the LEU stocks as of August 2012. These four SQs could be produced in 8.9-12.8 months.

If Iran were to deplete its supply of stored LEU in a breakout scenario, it would have to resort to a much slower pace to continue producing WGU. After depleting its LEU reserves, it would need 9.5-17 months to produce each additional SQ from natural uranium at the Natanz site, assuming its August 2012 infrastructure.

At the smaller Fordow facility, Iran would need at least 21 months to produce one SQ of WGU. This long period reflects the small number of centrifuges enriching uranium in August 2012.

Once Iran has a larger near 20 percent LEU stock, it could break out more quickly. However, these stocks may need to be larger than often expected. ISIS estimates that Iran would need about 320-380 kilograms of near 20 percent material to breakout in its single cascades at the Natanz Fuel Enrichment Plant, producing one SQ of WGU in a minimum of 0.9-1.7 months. The breakout times for tandem cascades at Natanz are slightly longer than for single cascades, reflecting the additional setup time required to form tandem cascades. But the more efficient tandem cascade arrangement would require far less 20 percent LEU for a breakout, roughly 180-230 kilograms. At Fordow, with all planned centrifuges operational and organized in tandem, Iran could break out in a minimum of 2.0-2.2 months. Iran would need a stock of about 200-220 kilograms of near 20 percent LEU hexafluoride to produce one SQ this way.

The fastest estimates given in this study combine the single cascades at the Natanz Fuel Enrichment Plant with the full capacity of the Fordow plant, assuming those cascades were organized in tandem. In this scenario, Iran could produce one SQ of WGU with 240-270 kilograms of near 20 percent LEU in a minimum of 0.8-1.0 months. If Iran instead formed new tandem cascades at the Fuel Enrichment Plant, it could break out with less material, roughly 190-200 kilograms of near 20 percent LEU, but the breakout would take slightly longer, at 1.3-1.4 months. The extra time results from the need to form tandem cascades at the Natanz plant.

Although Iran's breakout times are shortening, an Iranian breakout in the next year could not escape detection by the IAEA or the United States. Furthermore, the United States and its allies maintain the ability to respond forcefully to any Iranian decision to break out. During the next year or so, breakout times at Natanz and Fordow appear long enough to make an Iranian decision to break out risky. Therefore, ISIS assesses that Iran is unlikely to break out at Natanz or at Fordow in the near term, barring unforeseen developments such as a pre-emptive military strike.

Nonetheless, Iran's current trajectory at Fordow is increasing the chance of a military confrontation, particularly given growing concern about the relatively short breakout time at this facility once the plant is fully operational and once Iran has accumulated significantly more near 20 percent LEU hexafluoride. To reduce the tensions caused by Iran's increasing stocks of near

20 percent LEU and by the Fordow facility, a priority in the short term should be obtaining confidence building measures which would cap Iran's enrichment of uranium to five percent and limit the number of enriching centrifuges at the Fordow site to no more than a few hundred. It is in the interest of all concerned to avoid escalation of the Iranian nuclear crisis, first by negotiating such confidence building measures and then by negotiating more lasting agreements which ensure Iran will not build nuclear weapons.

Introduction

As Iran continues to stockpile enriched uranium, as well as increase its number of deployed centrifuges, assessing its ability to rapidly produce fissile material for nuclear weapons becomes ever more important. One option is for Iran to use its existing safeguarded nuclear facilities and nuclear materials to produce weapons-grade uranium (WGU, uranium enriched to 90 percent U-235).[2] This pathway would require Iran to violate or leave the Nuclear Non-Proliferation Treaty (NPT). During at least the next year, such a "breakout" or "dash" to enough WGU for a nuclear weapon would be visible to the inspectors of the International Atomic Energy Agency (IAEA). In pursuing this path, Iran would risk having its nuclear facilities crippled by a military strike, meaning it may currently be deterred from such action. However, as Iran has expanded its centrifuge program – the program most suited to a breakout – it has shortened considerably the time that would be required to produce enough WGU for a nuclear weapon. Iran may be seeking the ability to produce sufficient WGU faster than the IAEA inspectors could detect it.

For several years, experts at ISIS and the School of Engineering and Applied Science at the University of Virginia (UVA) have quantified Iran's ability to adapt its enrichment program to produce WGU. This report evaluates a variety of realistic breakout scenarios based on Iran's present and projected future abilities. So far, Iran has not enriched uranium beyond 20 percent; however, it maintains growing stockpiles of low-enriched uranium (LEU, uranium enriched up to 20 percent U-235) which exceed any realistic assessment of its need. These stockpiles bolster Iran's latent capability to manufacture a nuclear weapon. This study also considers the case when next year Iran is expected to have much larger quantities of near 20 percent enriched uranium which it could use to break out faster than today.

The estimates in this report 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. 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 is to prevent it from accumulating sufficient nuclear explosive material. This strategy in part depends on knowing how quickly Iran could make WGU.

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[2] Iran's pathways to nuclear weapons are discussed in a March 5, 2012 ISIS report prepared for the U.S. Institute of Peace, *Preventing Iran from Getting Nuclear Weapons: Constraining Its Future Nuclear Options*, available at http://isis-online.org/uploads/isis-reports/documents/USIP_Template_5March2012-1.pdf.

Background

Iran began feeding uranium hexafluoride into the centrifuge cascades at its main enrichment facility, the Fuel Enrichment Plant (FEP), near Natanz in February 2007. Over the next five years, Tehran increased the number of enriching centrifuges at Natanz to more than 9,000, added a set of tandem cascades in the Pilot Fuel Enrichment Plant (PFEP) at Natanz, and commenced enrichment at the fortified, underground Fordow Fuel Enrichment Plant (FFEP). Additionally, Iran has worked to improve its cascade design, recently moving from 15-stage to 17-stage cascades. While the IR-1 is not an advanced centrifuge, and while its performance in Iran has been subpar, Iran's IR-1 cascades still could be employed effectively in a breakout scenario.

The fastest breakout estimates rely on Iran's LEU stockpiles, namely its supplies of 3.5 and near 20 percent LEU, which are increasing with time. According to the August 2012 IAEA safeguards report on Iran, it has produced in total 6,876 kilograms (kg) of uranium hexafluoride enriched to 3.5 percent, some 1,567 kg of which has been further enriched at the PFEP or FFEP to produce 189.4 kg of uranium hexafluoride enriched to 19.75 percent.[3] As of August, Iran held a net 5,309 kg of 3.5 percent LEU hexafluoride and 116.5 kg of 19.75 percent LEU hexafluoride.[4] These stockpiles are monitored by the IAEA, but if Iran chose to break from its obligations under the NPT and expel IAEA inspectors, the stored LEU would become available for weapons production.

As of August, only 91.4 kg of near 20 percent LEU hexafluoride was stored at the enrichment plants. In a breakout scenario, it would be legitimate to include the additional 25.05 kg of this material stored at the uranium conversion facility near Esfahan, although this stock was scheduled to be fed into the conversion facility lines for conversion to an oxide form. The authors consider breakout potential with and without the extra 25 kg of near 20 percent material.

Any near 20 percent LEU that has already been converted to oxide form is not used in the breakout estimates because Iran would need at least a few months to convert it back to uranium hexafluoride. That time period is comparable to the time Iran would require to produce one significant quantity (SQ, twenty-five kilograms of WGU), an amount widely recognized as sufficient for a nuclear weapon. For this reason, Iran would not want to depend on the reconverted 20 percent LEU initially. However, the material could be used to obtain subsequent SQs or in the later part of a breakout that takes longer than 2-3 months. Finally, LEU oxide that has been irradiated in the Tehran Research Reactor would be difficult to reconvert to hexafluoride form. As of August 2012, the amount of irradiated 20 percent LEU was extremely small.

[3] Report by the IAEA Director General, *Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions in the Islamic Republic of Iran,* GOV/2012/37, August 30, 2012.

[4] See the *ISIS Analysis of the IAEA Safeguards Report*, *ISIS*, August 30, 2012. As of August, Iran had produced in total 189.4 kg of near 20 percent LEU hexafluoride. Some of the material (91.4 kg) was stored at the enrichment plants and some of it (1.6 kg) had been down blended. The remaining material (96.3 kg) was moved to the uranium conversion facility near Esfahan to make uranium oxide for the manufacture of fuel plates for the Tehran Research Reactor (TRR). Of this material, some (25.05 kg) was in the cylinder connected to the conversion facility. The rest (71.25 kg) had been fed into the conversion lines to produce some (31.1 kg) U_3O_8 product, with the remainder (40.15 kg) held up in the process lines or in the waste flow.

Methods

ISIS evaluated a range of breakout scenarios, almost all of which are based on a four-step enrichment method for producing WGU developed by the A.Q. Khan Research Laboratories in Pakistan. According to Khan's instructions, which Iran likely received, WGU can be produced from natural uranium (0.711 percent U-235) in a stepwise process by way of three approximate intermediate enrichments: 3.5 percent, 20 percent, and 60 percent. In addition to this four-step approach to obtain WGU, ISIS considered shortened three-step and two-step options that would rely on Iran's stockpiled LEU.

The secretive nature of Iran's centrifuge enrichment program makes efforts to gauge its performance challenging. The primary source of uncertainty is Iran's IR-1 centrifuge. Drawing on information obtained by ISIS as well as published data, the authors predict the enrichment characteristics of Iran's IR-1 machines for various operating conditions, and these estimates undergird the subsequent analysis. This technique attempts to capture performance limitations absent from other popular methods, such as separative work calculators. ISIS models Iran's actual infrastructure rather than relying on idealized calculations.[5]

ISIS pairs surmised IR-1 enrichment characteristics and known Iranian cascade structures to develop predictive computer models for assessing cascade performance.[6] These hypothetical cascades are used to evaluate various breakout pathways, generating a mathematical minimum estimate for the time required to accomplish the breakout. The cascade models make predictions which agree reasonably well with their physical counterparts;[7] but even so, a real enrichment facility never operates seamlessly.

To account for setup time and other inescapable delays, ISIS adds two weeks to each raw estimate. This time period allows for a range of necessary modifications, including valve adjustments which would close off certain centrifuges or alter flow rates within the enriching cascades. It also assumes the operators would modify or change the cold traps in some of the withdrawal sections of the plants so that they could hold 60 and 90 percent enriched uranium safely without an undue risk of the HEU becoming critical, a serious accident which would threaten the entire breakout operation. Since IAEA inspectors would typically notice these types of changes, Iran would likely wait to start making them until after inspectors were no longer allowed in the plant. For breakout scenarios which require the formation of new tandem cascades, ISIS adds an additional two weeks, or four weeks total. This extra time would be needed to re-pipe single cascades into tandem sets.

[5] Iran's enrichment facilities are not ideally suited for producing WGU. A large scale reconfiguration might allow Iran to achieve breakout times closer to those predicted by a separative work calculator. However, reconfiguring each IR-1 cascade at Natanz and Fordow to such a great extent would in itself take longer than the breakout estimates contained in this report. The authors did not include this case.

[6] The method is related to that reported by Migliorini and Wood; see Migliorini, PJ and Wood, HG, A Study of Multicomponent Streams in Off-Design Centrifuge Cascades, *Separation Science and Technology* 4**7**, 8 (2012).

[7] The separative performance of Iran's IR-1 cascades has been roughly 0.7-0.9 kg-SWU/yr. ISIS's computer models make performance predictions generally within this range.

Examining the Breakout Scenarios

The breakout scenarios examined in this report are differentiated by four factors, listed below.

Breakout Location: Natanz, Fordow, or both

Breakout could occur at the Natanz Fuel Enrichment Plant, near the city of Natanz, or at the Fordow Fuel Enrichment Plant, near the city of Qom, or at both together. The Natanz facility is larger and contains significantly more centrifuges, but is more vulnerable to foreign air strikes. While the Fordow plant is built into the side of a mountain and is far more fortified than the Natanz facility, it too could be impacted by a military strike. In particular, a U.S. strike could halt operations at Fordow for many months, even if the strike could not guarantee complete destruction of the deeply buried cascade halls and contained centrifuges. Furthermore, tunnel entrances, electrical supplies, water supplies for cooling centrifuges, ventilation shafts, and other supporting equipment could be destroyed by military strikes. In theory, the United States could carry out these strikes over a sustained period of time to ensure that the enrichment operations did not resume or that Iran could not disassemble and move the centrifuges from the Fordow site to a secret site.

Breakout Process: Four-Step, Three-Step with Stockpiles, or Two-Step with Stockpiles
ISIS considered the four-step A.Q. Khan procedure, as well as two modified procedures which rely on Iran's LEU stockpiles.

Four-Step: This original A.Q. Khan procedure would allow Iran to manufacture WGU on a continuous basis, beginning with natural uranium hexafluoride. While this process is by far the slowest, Iran could use it to produce WGU continuously for a considerable length of time given the size of its existing supply of natural uranium hexafluoride. Using this method, Iran would enrich natural uranium to 3.5 percent, then to 20 percent, and then to 60 percent, before producing WGU.

Three-Step with Stockpiles: Iran could conceivably use its 3.5 and near 20 percent LEU stockpiles to skip the first step in the Khan process, converting its stored material to WGU. In this case, Iran would continue to produce 19.75 percent LEU from its stockpile of 3.5 percent LEU, but it would not use any centrifuges to produce new 3.5 percent material. ISIS assesses that Iran has stockpiled enough LEU to pursue this option; however, absent a tails recycling strategy, Iran could only produce a handful of SQs this way. After depleting its LEU stockpile, Iran would have to revert to the slower four-step process to continue producing WGU, dramatically constraining its ability to produce many SQs in a timely manner.

Two-Step with Stockpiles: With a large enough near 20 percent uranium hexafluoride stockpile, Iran could forgo both steps one and two in a rapid dash to one significant quantity of WGU. Iran could not employ this strategy until after it enriched sufficient 19.75 percent enriched uranium for more than one significant quantity, perhaps significantly more, since some losses are inevitable with IR-1 cascades. In this scenario, all centrifuges would be devoted to producing 60 and 90 percent enriched uranium, and Iran would not replenish its 19.75 percent or 3.5 percent stockpiles. ISIS assesses that Iran does not currently possess enough 20 percent LEU hexafluoride to pursue this option (even when its oxide forms of the material are included), although it could reach the required amount in the last part of 2012 or more likely the first half of 2013.

Natanz Cascade Restructuring: No Restructuring or Conversion to Tandem Cascades

Iran could produce WGU more quickly at Natanz by restructuring some of its cascades.[8] One simple option is to employ multiple "tandem cascades," a design which pairs two cascades so that the second recycles a portion of the waste generated by the first. Iran has achieved slight improvements in centrifuge efficiency with this type of cascade, which it uses to enrich 19.75 percent LEU from 3.5 percent LEU at both the FFEP and PFEP. At present, Iran has deployed the tandem design only on a small scale. The cascades that currently produce 3.5 percent LEU at the FEP (the main hall at Natanz) are arranged as single cascades. For the purposes of this report, ISIS considered two possibilities: (1) no large-scale cascade restructuring at Natanz and (2) cascade restructuring limited to the formation of new tandem cascades.

Fordow Enriching Capacity: Present or Future

Iran appears to be prioritizing the Fordow facility over the Natanz facility for new installations of IR-1 centrifuges. It appears to be limited in the raw materials needed to build large numbers of additional IR-1 machines. Currently, Iran is enriching in four cascades at Fordow, approximately one-fourth of the facility's total capacity. The four cascades are arranged in two sets in the tandem fashion. Iran has installed centrifuges in eight additional cascades at Fordow, and partially installed a ninth additional, but is not enriching in these cascades. As of August 2012, most of the newly installed centrifuges were not yet connected by piping. Iran's stated purpose for the Fordow facility is to produce LEU enriched up to 20 percent, so it seems most likely that the new cascades will be connected in the tandem fashion. However, a clear structure was not yet apparent in the bulk of the installed cascades, and the IAEA could not tell whether the new cascades will be organized in tandem. ISIS considered two possibilities in this study: (1) the enriching capacity at Fordow presently and (2) the full enriching capacity at Fordow, assuming all new cascades are arranged in tandem.

[8] Only one, simple, reconfiguration option is considered, not the large-scale reconfiguration mentioned previously.

Results

ISIS considered numerous breakout scenarios. The four primary factors which differentiate them are the breakout location, the breakout process, whether new tandem cascades were formed at the Natanz FEP, and the enriching capacity of the Fordow facility. Within each of these categories, ISIS conducted multiple simulations with slightly varying parameters. The estimated breakout times are reported in range format. *Each stated range was generated with the evaluation method – and the limitations – described above, and should be interpreted as a best estimate, not as an absolute minimum or maximum.* The results are reported in months, generally to one or two significant figures for clarity, although the authors freely acknowledge that the level of uncertainty precludes any high precision estimate.

Part One: Current Breakout Potential

ISIS assesses that presently, using its current infrastructure and LEU stockpiles, Iran could break out with a four-step process or a three-step process. The breakout could occur at Natanz, at Fordow, or at a combination of the two facilities.

Four-Step Process at Natanz

Table 1 summarizes predictions for a four-step breakout at the Natanz FEP. Eight simulations are reported, of which five considered slight variations on the single cascades currently installed at the FEP, and three considered the case in which new tandem cascades would be formed at the FEP. These simulations did not incorporate Iran's existing LEU supplies. Instead, they started with natural uranium hexafluoride and could be repeated continuously.

ISIS estimates that, using a four-step process at the Natanz FEP, Iran would require at least 14.5-17 months to produce one SQ with its single cascades. If Iran were to reconfigure some cascades into the tandem format, ISIS estimates that at least 9.5-13 months would be required for one SQ.

Table 1: Four-Step Process at Natanz

Scenario		Setup Time (months)	Enriching Time (months)	Total Time (months)
Single Cascades	1	0.5	14	14.5
	2	0.5	16.5	17
	3	0.5	13.5	14
	4	0.5	14.5	15
	5	0.5	14	14.5
New Tandem Cascades	6	1	9	10
	7	1	12	13
	8	1	8.5	9.5

Table 1. Estimated times (in months) for Iran to produce one SQ are given based on a four-step breakout process at the Natanz FEP. Eight simulations were performed, each with slightly varied parameters. The final estimates are formed by adding the expected setup time to the expected enriching time. This enrichment strategy does not rely on LEU stockpiles and could be repeated so long as Iran possessed an ample supply of natural uranium.

Three-Step Process at Natanz

With the three-step process, Iran would utilize its stored LEU to produce one (or a few) SQ(s) more quickly. Its 3.5 percent and 19.75 percent stocks would be used as feed for the second and third steps in the Khan process, eliminating the need for the first step (natural uranium to 3.5 percent). Predicted breakout times for this approach are summarized in Table 2. The estimates are made assuming the stockpile sizes reported in the August 2012 IAEA Iran safeguards report. One set of predictions is made with the near 20 percent LEU hexafluoride stock taken as 91.4 kg, and a second set is made which includes the extra 25 kg of the same material stored at the uranium conversion facility. The second set of calculations shows how the breakout times generally decrease as the stockpile sizes increase. Again, eight simulations are reported, some based on the single cascades currently installed at the FEP, and the rest assuming that new tandem cascades would be formed at the FEP. Iran could not follow this strategy indefinitely because its LEU stockpiles are limited.

ISIS estimates that, using a three-step process at the Natanz FEP, Iran would require at least 2.5-4.1 months to produce one SQ with its single cascades if it only used the LEU hexafluoride stored at enrichment facilities, and at least 2.3-2.5 months if it also used the LEU hexafluoride currently scheduled for conversion to oxide form. If Iran were to reconfigure some cascades into the tandem format, ISIS estimates that at least 2.3-2.7 months would be required for one SQ if the extra LEU hexafluoride is excluded, and at least 2.0-2.3 months if the extra LEU hexafluoride is included.

Table 2: Three Step Process at Natanz

Scenario		Setup Time (months)	Enriching Time (months)	Total Time (months)	Enriching Time Extra 25 kg 20% UF6 (months)	Total Time Extra 25 kg 20% UF6 (months)
Single Cascades	1	0.5	2.0	2.5	2.0	2.5
	2	0.5	3.6	4.1	1.9	2.4
	3	0.5	2.0	2.5	2.0	2.5
	4	0.5	2.5	3.0	2.0	2.5
	5	0.5	2.0	2.5	1.8	2.3
New Tandem Cascades	6	1	1.3	2.3	1.1	2.1
	7	1	1.7	2.7	1.0	2.0
	8	1	1.3	2.3	1.3	2.3

Table 2. Estimated times (in months) for Iran to produce one SQ with a three-step process are given based on its August 2012 LEU stockpiles. Two sets of enriching times are given, one excluding the 25 kg of near 20 percent LEU hexafluoride stored at the conversion facility, and one including it. Eight simulations were performed with slightly varying parameters. The final estimates are formed by adding the expected setup time to the expected enriching time.

At this time, Iran could dash to one SQ most quickly with the three-step process at the Natanz FEP. However, it could only produce a few SQs in this manner before depleting its LEU stockpiles. Table 3 shows that Iran could produce at most two SQs this way with its single cascades, and at most four SQs if it formed new tandem cascades. Notice that in order to conserve enough feed to produce multiple SQs, Iran would have to run its cascades more conservatively and would have to wait longer for the first SQ. In the case of single cascades, Iran might attempt a tails recovery strategy after a three-step breakout, re-enriching the waste from its cascades to obtain a few additional SQs. Not surprisingly, tandem cascades, which include some measure of tails recycling in their design, would allow Iran to more effectively convert its LEU into WGU.

Table 3: Multiple Significant Quantities Using the Three-Step Process at Natanz

Scenario		Time for One SQ (months)	Time for 1st/2nd SQs (months)	Time for 1st/2nd/3rd SQs (months)	Time for 1st/2nd/3rd/4th SQs (months)
Single Cascades	1	2.5	4.4/8.3	x	x
	2	4.1	x	x	x
	3	2.5	2.6/4.6	x	x
	4	3.0	3.1/5.7	x	x
	5	2.5	3.0/5.5	x	x
New Tandem Cascades	6	2.3	2.7/4.3	2.7/4.5/6.2	3.0/5.0/6.9/8.9
	7	2.7	4.0/6.9	3.9/6.9/9.8	4.0/6.9/9.9/12.8
	8	2.3	2.5/3.9	2.6/4.1/5.7	3.1/5.2/7.3/9.4

Table 3. Estimated times (in months) for Iran to produce multiple SQs are given based on its August 2012 LEU stockpiles. Eight simulations were performed, with slightly varied input parameters. The final estimates are formed by adding the expected setup time (0.5 months for single cascades at Natanz and one month for new tandem cascades at Natanz) to the expected enriching time. The setup time is only added to every raw estimate, but only once, even if the scenario produces multiple SQs. An 'x' indicates that the scenario under consideration could not produce the relevant number of SQs with the available LEU.

Four- and Three-Step Processes at Fordow, August 2012 Capacity

At this time, the enriching capacity of the Fordow facility is small enough to preclude a rapid breakout there. In August, only 696 IR-1 centrifuges were enriching at Fordow. Estimates for a four- and three-step breakout at Fordow are given in Table 4.

ISIS estimates that, at the Fordow enrichment facility operating with August 2012 capacity, Iran would require at least 150 months to produce one SQ with a four-step process, and at least 21 months to produce one SQ with a three-step process and its LEU stockpiles.

Table 4: Four- and Three-Step Processes at Fordow, August 2012 Capacity

Current Capacity	Setup Time (months)	Enriching Time (months)	Total Time (months)
Four-Step Process	0.5	149.5	150
Three-Step Process	0.5	20.5	21

Table 4. Estimated times (in months) for Iran to produce one SQ with a four-step process and with a three-step process are given based on its August 2012 LEU stockpiles.[9] The final estimates are formed by adding the expected setup time to the expected enriching time.

Combined Breakout at Natanz and Fordow

At this time, the enriching capacity of the Natanz FEP dwarfs that of the Fordow facility. ISIS considered scenarios which enlisted Natanz and Fordow simultaneously, but the breakout estimates were not significantly different from the predictions made using the Natanz facility alone. Any slim decreases in enriching time were negated by the increased complexity of transferring material between the two facilities. However, if the Fordow facility were enriching at full capacity, its impact on the minimum breakout time would no longer be negligible. This is one scenario considered below.

Part Two: Future Breakout Potential

Four- and Three-Step Processes at Fordow

Iran appears to be prioritizing the Fordow facility for new IR-1 installation. The facility is built to hold 2,784 centrifuges. It is reasonable to expect that the Fordow facility could be operating at full capacity sometime in the first half of 2013, given that Iran has already installed three-fourths of the necessary centrifuges. Estimates for a four- and three-step breakout at Fordow which reflect the expected increases in capacity are given in Table 4. The three-step prediction is made based on Iran's August 2012 stockpile sizes.[10] Most likely, these stockpiles will change over the next few months. With greater 3.5 percent and near 20 percent supplies, Iran could break out more quickly and produce more SQs.

ISIS estimates that, at the Fordow facility in 2013, assuming its August 2012 LEU stockpiles, Iran would require at least 38 months to produce one SQ with a four-step process and at least 5.5 months to produce one SQ with a three-step process and its LEU supplies.

[9] The near 20 percent LEU hexafluoride stockpile is taken as 91.4 kg.
[10] The near 20 percent LEU hexafluoride stockpile is taken as 91.4 kg.

Table 5: Four- and Three-Step Processes at Fordow, Full Capacity

Full Capacity	Setup Time (months)	Enriching Time (months)	Total Time (months)
Four-Step Process	0.5	37.5	38
Three-Step Process	0.5	5.0	5.5

Table 5. Estimated times (in months) for Iran to produce one SQ are given based on a four-step process, and on a three-step process and Iran's August 2012 LEU stockpiles. The final estimates are formed by adding the expected setup time to the expected enriching time.

Two-Step Process at Natanz

If Iran produces enough near 20 percent LEU, it could break out in two steps rather than three, devoting all cascades to further enriching that material. In these scenarios, Iran does not replenish its 3.5 percent or 19.75 percent LEU. Iran does not currently possess enough and is not expected to have such large quantities of near 20 percent LEU until at least late 2012 or more likely sometime in 2013. Table 6 lists the amount of near 20 percent feed as well as the estimated time required to produce one SQ using this method at Natanz. The estimated feed requirement varies considerably, with much more 20 percent material needed in the simulations involving single cascades. The tails recycling feature of the tandem cascades helps them conserve feed. In both cases, the estimated setup time is generally longer than the estimated enriching time.

ISIS estimates that, using a two-step process at the Natanz FEP, Iran would require at least 0.9-1.2 months and 320-380 kg of near 20 percent LEU hexafluoride to produce one SQ with single cascades. If Iran were to form new tandem cascades, ISIS estimates that it could produce one SQ in a slightly longer 1.4 to 1.7 months, but would require only 180-230 kg of near 20 percent feed.

Table 6: Two-Step Process at Natanz

Scenario		Required 20% Stockpile (kg UF6)	Setup Time (months)	Enriching Time (months)	Total Time (months)
Single Cascades	1	320	0.5	0.4	0.9
	2	380	0.5	0.4	0.9
	3	320	0.5	0.7	1.2
New Tandem Cascades	4	180	1	0.7	1.7
	5	200	1	0.5	1.5
	6	200	1	0.5	1.5
	7	230	1	0.4	1.4

Table 6. Estimated times (in months) as well as estimated 20 percent stockpile requirements for Iran to produce one SQ are given based on a two-step process at the Natanz FEP. The final estimates are formed by adding the expected setup time to the expected enriching time.

Two-Step Process at Fordow

The same two-step strategy could be employed at the Fordow facility. Again, Iran does not currently possess a large enough 20 percent stockpile for this process, but will likely have enough 20 percent material in late 2012 or sometime in 2013. Table 7 gives the estimated time and near 20 percent LEU hexafluoride feed requirements for a two-step breakout at Fordow, assuming it operates at full capacity and that its cascades are arranged in tandem pairs.

ISIS estimates that, using a two-step process at the Fordow facility in 2013, Iran would require at least 2.0-2.2 months and 200-220 kg of near 20 percent LEU hexafluoride feed to produce one SQ.

Table 7: Two Step Process at Fordow

20% Stockpile (kg UF6)	Setup Time (months)	Enriching Time (months)	Total Time (months)
200	0.5	1.7	2.2
220	0.5	1.5	2.0

Table 7. Estimated times (in months) as well as estimated near 20 percent LEU hexafluoride stockpile requirements are given for Iran to produce one SQ with a two-step process at Fordow. The Fordow facility is assumed to be operating at full capacity with its cascades arranged in the tandem formation. The final estimates are formed by adding the expected setup time to the expected enriching time.

Two-Step Process at Natanz and Fordow Together

Assuming the Fordow facility operates at full capacity, Iran could combine it with the Natanz FEP for the fastest two-step breakout. Furthermore, by combining the single cascades at Natanz with the tandem cascades at Fordow, Iran could achieve a rapid breakout with only a moderate amount of near 20 percent LEU. Table 8 gives estimated breakout times generated using this strategy.

ISIS estimates that, using a combined two-step process at the Natanz FEP and at the Fordow facility in 2013, Iran would require at least 0.8-1.0 months and 240-270 kg of near 20 percent LEU hexafluoride to produce one SQ with its single cascades at Natanz. If Iran were to form new tandem cascades at Natanz, ISIS estimates that Iran could produce one SQ in a slightly longer period of time, 1.3-1.4 months, but would require only 190-200 kg of near 20 percent LEU feed.

Table 8: Two-Step Process at Natanz and Fordow Together

Scenario		Required 20% Stockpile (kg UF6)	Setup Time (months)	Enriching Time (months)	Total Time (months)
Single cascades at Natanz; Tandem cascades at Fordow	1	250	0.5	0.4	0.9
	2	270	0.5	0.3	0.8
	3	240	0.5	0.5	1.0
	4	270	0.5	0.3	0.8
	5	270	0.5	0.4	0.9
Tandem cascades at both Natanz and Fordow	6	200	1	0.3	1.3
	7	190	1	0.4	1.4
	8	190	1	0.4	1.4

Table 8. Estimated times (in months) as well as estimated 20 percent LEU hexafluoride stockpile requirements are given for Iran to produce one SQ using a two-step process at Natanz and Fordow together. The shortest times assumed that all the cascades at Fordow were dedicated to step 4, enriching from 60 to 90 percent. The final estimates are formed by adding the expected setup time to the expected enriching time.

Findings

In making its breakout estimates, ISIS seeks to identify the minimum time that would be required for Iran to accumulate enough weapons-grade uranium for a nuclear weapon. In practice, Iran might require more time than predicted. That is, Iran may know in theory how to produce weapons-grade material, but in practice it might encounter difficulties and unexpected inefficiencies. Thus far, Iran seems to have found enrichment operations difficult and more time consuming than expected, and it has encountered sometimes substantial losses in enrichment output which necessitated the use of more feed than planned. Furthermore, prior to making the decision to break out and produce WGU, Iran might desire a high level of confidence about its ability to avoid detection. Finally, it may want to produce enough WGU for more than a single nuclear weapon. For all of these reasons, Iran could very well require more time to break out and produce one SQ than is suggested by these minimum estimates.

Iran would also need several months to convert its WGU into the components of a nuclear weapon and assemble a complete device. Regardless of the extent of its past or on-going nuclear weaponization activities, Iran has not made a nuclear weapon and likely has not mastered the technology to weaponize WGU. Therefore, Iran would have to overcome new technological hurdles before it could manufacture a nuclear weapon successfully.

Current Breakout Potential

Based on the size of Iran's LEU stockpiles as of August 2012, ISIS estimates that Iran would require at least two months in the fastest case to dash to one significant quantity of WGU. The estimate is at least 2.3-4.1 months if Iran's stock of near 20 percent LEU hexafluoride is taken as 91 kg, and at least 2.0-2.5 months if this stock is 25 kg greater. These estimates assume a breakout at the Natanz FEP. In an earlier ISIS calculation from the first part of 2012, the breakout estimate at Natanz was four months.[11] The shorter estimate given in this report reflects Iran's improved cascade operations and its additional stored LEU, particularly its near 20 percent LEU hexafluoride. One can see that the estimated breakout time decreases with the accumulation of more 20 percent LEU. The breakout times tend to drop incrementally, and sometimes significantly. Once Iran reaches certain levels of 20 percent LEU, it need not devote as many cascades to producing this material in a breakout scenario, leaving more cascades free to produce highly enriched uranium (HEU).

Current breakout times at the Fordow enrichment plant are much longer than those possible at the Natanz site. This conclusion reflects the relatively smaller number of IR-1 centrifuges enriching at the Fordow site as of August 2012.

Minimum breakout times assume Iran would focus on producing only one SQ of weapons-grade uranium. To do so as fast as possible, the simulations use up a considerable amount of Iran's stored LEU. If Iran wanted multiple SQs it could use its LEU more judiciously, but as a consequence it would require more time for the first SQ. With its August 2012 stockpiles, ISIS

[11] ISIS, *Preventing Iran from Getting Nuclear Weapons: Constraining Its Future Nuclear* Options, available at http://isis-online.org/uploads/isis-reports/documents/USIP_Template_5March2012-1.pdf.

estimates that Iran could make only two SQs using its single cascades at Natanz, requiring a period of 4.6-8.3 months. Tandem cascades at Natanz could make two SQs somewhat faster – in 3.9-6.9 months – and would leave enough stored LEU to make two additional SQs. These four SQs could be produced in 8.9-12.8 months. In a breakout scenario, Iran's goals would largely depend on its motivations; however, it is unlikely that Iran would be willing to incur the consequences of breaking out from the NPT for only one nuclear weapon.

If Iran were to use up its stored LEU in a breakout scenario, it would have to resort to a much slower pace to continue producing WGU. After depleting its LEU reserves, it would need 9.5-17 months to produce each additional SQ from natural uranium, assuming its August 2012 infrastructure.

Future Breakout Potential

Once Iran has a larger near 20 percent LEU stockpile, it could break out more quickly. ISIS estimates that with about 320-380 kg of near 20 percent material, Iran could use its single cascades at the Natanz FEP to produce one SQ in a minimum of 0.9-1.7 months. The breakout times for tandem cascades at Natanz are slightly longer than for single cascades, reflecting the longer setup time required to form tandem cascades. But a tandem cascade arrangement would require far less 20 percent LEU for a breakout, roughly 180-230 kg.

At Fordow, with all planned centrifuges operational and organized in tandem, Iran could break out in a minimum of 2.0-2.2 months. Iran would need a stock of about 200-220 kg of near 20 percent LEU hexafluoride to produce one SQ this way.

The fastest estimates given in this study were generated by combining the single cascades at the Natanz FEP with the full capacity of the Fordow plant, assuming those cascades were organized in tandem. In this scenario, Iran could produce one SQ with 240-270 kg of near 20 percent LEU, requiring an estimated minimum of 0.8-1.0 months. If Iran instead formed new tandem cascades at the FEP, it could break out with less material, roughly 190-200 kg of near 20 percent LEU, but the breakout would take slightly longer, at 1.3-1.4 months. The extra time results from forming tandem cascades at the FEP.

Discussion and Recommendations

Despite the declining breakout times, ISIS assesses that Iran is unlikely to break out at Natanz or at Fordow in the near term (this year or well into next year), barring unforeseen events such as a pre-emptive military strike. These sites are monitored by the IAEA and closely followed by U.S. and other intelligence agencies, meaning that Iranian production of WGU could not evade detection. Iran's potential nuclear weapons capabilities are growing, but Iran could not yet break out without avoiding detection by the IAEA or the United States. Furthermore, the United States and its allies have the ability to respond quickly to any Iranian breakout.

Nonetheless, although the existing detection capabilities are sound, every effort should be taken to improve them, both through improved IAEA monitoring inside the facilities and U.S. and allied intelligence operations. The IAEA should visit Iranian enrichment facilities once a week on average, or even more frequently. The IAEA should also conduct unannounced inspections more often to deflate any Iranian expectation that it would have a set amount of time within which, should it decide to break out, it could avoid detection. Perhaps more importantly, regardless of Iranian intentions, unannounced inspections would provide an important confidence building measure for the United States and its allies, including Israel.

It is natural to consider how Iran could significantly reduce its breakout time in the future. The most obvious answer is to increase by thousands the number of enriching IR-1 centrifuges, for example at the Natanz Fuel Enrichment Plant, which has enough outer casings installed to hold about 6,000 more IR-1 machines. However, Iran appears to face shortages of raw materials necessary to build thousands of IR-1 centrifuges. Yet, there is another possibility. Iran could deploy advanced centrifuges at the Fordow enrichment plant or possibly at a third enrichment site. Its advanced centrifuges, principally the IR-2m and perhaps the IR-4 models, are expected to achieve about 3-4 times the enrichment output of the IR-1 centrifuges. Iran is currently testing both types in production-scale cascades at the Natanz Pilot Fuel Enrichment Plant but making progress at a much slower rate than expected. However, with advanced centrifuges, Iran could increase by several-fold its production of 19.75 percent LEU and it could break out with far fewer (less than 1,000) machines. For this reason, any deployment of advanced centrifuges will inevitably increase tensions.

Despite an Iranian decision to breakout being unlikely during the next year or so, Iran's current trajectory at Fordow is increasing the chance of a military confrontation. There is growing concern about the relatively short breakout time at Fordow once the plant is fully operational and Iran has accumulated enough near 20 percent LEU for the production of one significant quantity of WGU.

To reduce the tensions caused by Iran's increasing stocks of near 20 percent LEU and by the Fordow facility, a priority in the short term should be obtaining confidence building measures which would cap Iran's enrichment of uranium to five percent and limit the number of enriching centrifuges at the Fordow site to no more than a few hundred. It is in the interest of all concerned to avoid escalation of the Iranian nuclear crisis, first by negotiating such a confidence building measure and then by negotiating lasting agreements which ensure Iran will not build nuclear weapons.