INSTITUTE FOR SCIENCE AND INTERNATIONAL SECURITY
REPORT

# Breakout Timelines Under the Joint Comprehensive Plan of Action

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*A critical criteria of the Joint Comprehensive Plan of Action (JCPOA) is a twelve month breakout timeline for Iran's remaining gas centrifuge program. However, this 12 month criteria does not hold if Iran were to re-install the advanced IR-2m centrifuges during a breakout. Breakout timelines of seven months result if these centrifuges are re-installed. The U.S. administration makes the assessment that Iran will not re-install these centrifuges because they are unreliable and work poorly. This assessment preserves a 12-month breakout timeline but it appears questionable. The JCPOA has many strengths but one of its most serious shortcomings is that it almost ensures that Iran can emerge in 15-20 years as a nuclear power with the potential, at a time of its choosing, to make enough weapon-grade uranium for several nuclear weapons within a few weeks. Addressing this weakness, in particular by finding ways to ensure Iran does not build a semi-commercial enrichment program, should become a critical part of the implementation of the JCPOA and not left to future generations of decision makers.*

## Introduction and Summary

A key criterion in the development of the Joint Comprehensive Plan of Action (JCPOA) is the time Iran needs to produce enough weapon-grade uranium for a nuclear weapon, called breakout. The administration has used a 12-month breakout criterion in designing limits on Iran's gas centrifuge program. The bare-boned limits on Iran's centrifuge program provide for at least a 12-month breakout period. However, based on ISIS analyses the agreed limits do not guarantee a 12-month breakout timeline during the first ten years of the agreement, if Iran can relatively quickly re-deploy its already manufactured IR-2m centrifuges. The administration has taken the position that Iran will not deploy these IR-2m centrifuges, because they have assessed that they will not work well enough. However, this assessment depends on an assumption about Iran's manufactured IR-2m centrifuges that may not hold. Moreover, available data indicate that the breakage rate of the IR-2m centrifuges are no worse than those for the IR-1 centrifuges. Uncertainties about the quality of the existing IR-2m centrifuges make a definitive resolution of this issue difficult. Nonetheless, straightforward prudence would argue to include these centrifuges in a breakout, since their redeployment would have a major impact compared to IR-1 centrifuges and the United States lacks high assurance that the IR-2m centrifuges will not work adequately if deployed. In this case, the 12-month breakout criterion

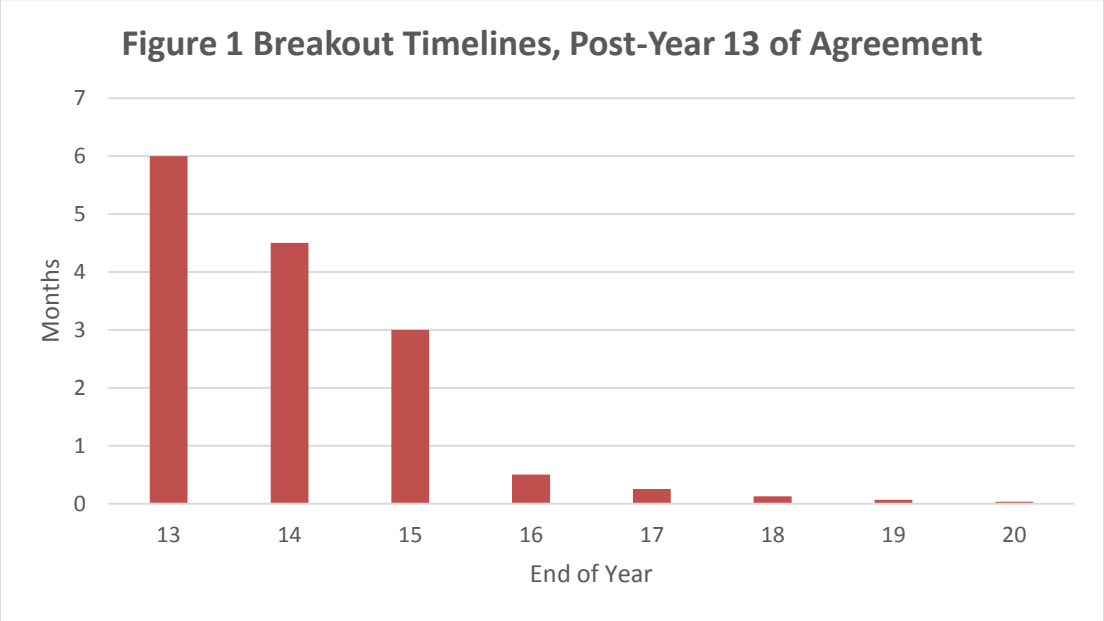
does not hold during the first ten years of the agreement. At a minimum, it is arguable whether the breakout criterion holds.

**Recommendation.** Regardless of the difference about the breakout estimate, the United States should ensure, via additional discussions with Iran, that IR-2m centrifuges are dismantled in a manner to ensure that they are more difficult, if not impossible, to redeploy quickly in a breakout.

After ten years, the breakout timeline is expected to decrease, as Iran expands its centrifuge program. Based on discussions with knowledgeable U.S. and E3 officials, the breakout timeline will be approximately six months in year 13 of the agreement. Afterwards, it is expected to decrease further, if Iran builds centrifuges according to its stated plans. In year 15, the breakout timeline could have shrunk to about three months. But soon after year 15, breakout could decrease rapidly to a few weeks, as the cap on Iran's low enriched uranium (LEU) stock ends and it can resume making near 20 percent. Within a few years after year 15, the breakout timeline can reach a few days, assuming resumed production of near 20 percent LEU and the installation of thousands of Iran's advanced centrifuges. Constructing a large, commercial-scale enrichment program is a goal stated by Iranian officials on numerous occasions.

## Table 1 Breakout Timelines in JCPOA

| Year(s) | Breakout (months) | Comments |
|---|---|---|
| 1 to 10 | 7-13 | IR-2m centrifuges re-installed in lower bound |
| 13 | 6 | |
| 15 | 3 | Cap on LEU intact, no near 20% LEU produced |
| Mid-16 | 1.5-2 | No cap on 3.5% LEU |
| End-16 | 0.5 | Resumed production of near 20% LEU |
| 18 to 20 | few days | Installation of large number of advanced centrifuges |



This potentially dangerous buildup in capacity will occur as inspection and monitoring arrangements specific to gas centrifuges start to curtail, including:[1]

- The important provision to allow speedy resolution of IAEA access concerns ends after year 15.
- The procurement channel, as established under the JCPOA and the U.N. Security Council, which limits Iranian procurement for its centrifuge program and provides important transparency over key procurements for the centrifuge program ends after ten years. Whatever replaces it after year 10 will be far less limiting of imports for Iran's centrifuge program.
- IAEA regular access, including daily access as requested by the IAEA, to relevant buildings at Natanz, including all parts of the FEP and PFEP will end after 15 years.[2]
- Natanz being the sole location for all of Iran's uranium enrichment related activities including safeguarded research and development will end after 15 years.[3]
- The limitation on Iran engaging with any foreign entity in enrichment or enrichment-related activities only with approval by the Joint Commission ends after 15 years.[4]
- The use of IAEA approved and certified modern technologies, including on-line enrichment measurement and electronic seals, issuing long-term visas to the inspectors, and designating 130-150 IAEA inspectors are in place for 15 years or longer, which means that their continuation after year 15 is subject to further negotiations.[5]

Importantly, the Additional Protocol is slated to remain in force in perpetuity and there will be transparency over uranium for 25 years. However, the Additional Protocol by itself is not adequate if Iran dramatically ramps up its centrifuge program, and similarly for the provision on uranium monitoring. With important, intrusive inspection arrangements slated to end under the JCPOA after year 15, the effectiveness of the remaining verification measures at detecting Iranian breakout fast enough at either covert or overt sites becomes doubtful.

Combined with the ending of important supplementary verification measures after year 15, the increase in enrichment capacity after a ten year hiatus remains one of the major weaknesses of this agreement. Thus, any consideration of the JCPOA should carefully weigh its long-term prospects. One may argue that buying ten, perhaps fifteen years, is sufficient by itself and that after ten or fifteen years the United States will have the same leverage as it has today to confront Iran over its nuclear weapons capabilities or any movement toward nuclear weapons. However, at that point, this U.S. leverage may not exist or be severely constrained. That the United States may be in a worse position ten to fifteen years from now to influence Iran's nuclear plans should be a key consideration of evaluating the JCPOA. Ten years after the 1994 U.S./North Korean Agreed Framework was signed, North Korea had renounced this framework and was in the process of building nuclear weapons. At the time, the United States and its allies

[1] See paragraph 15 main text of JCPOA and paragraphs of Annex I.
[2] See paragraph 71 in Annex I. Some of this access is redundant with the Additional Protocol.
[3] See paragraph 72 in Annex I.
[4] See paragraph 73 in Annex I.
[5] See also paragraph 67 in Annex I.

were poorly positioned to stop North Korea, or even judge accurately when it would actually cross the threshold of possessing nuclear weapons. Looking back to ten years after the signing of the Agreed Framework, the United States had lost the valuable leverage it had had in 1994 when it negotiated the agreement.

Given the volatility of the Middle East, firm predictions about substantial, effective U.S. leverage ten years from now should be viewed more as speculation and a hope than as credible projections. While some voice confidently that Iran will change for the better over the next ten to fifteen years, similar or same voices also said this ten to fifteen years ago. In the last ten years, events in the Middle East have not unfolded as predicted, let alone as expected. Today, Iran can hardly be called more responsible or friendly to U.S. interests than it was ten years ago. It should also be remembered that the ten year limitation on Iran's centrifuge program, despite its value, is already a compromise of the initial E3 goal of ten years ago to achieve up to a ten-year suspension in Iran's centrifuge program. And this compromise took 12 years to negotiate. So, ten-year nuclear limitations are not as lengthy as they seem, given how long the Iranian nuclear debacle has lasted, how little the onerous aspects of the Iranian regime have changed, how unpredictable the Middle East has proven to be, and how U.S. leverage may not be sufficient to stop Iran from building nuclear weapons ten to fifteen or more years from now.

Supporters of the agreement have not offered answers regarding how to avoid a dire outcome after 10 to 15 years. Often, one hears that if Iran breaks out or otherwise seeks nuclear weapons, the United States can bomb Iran. However, this option appears unworkable as a prescriptive policy, given how close Iran can be to having nuclear weapons in 15 years, how much greater its conventional military capabilities will likely be, and how U.S. decision makers will likely resist launching military strikes against Iran or any other country.

Others state that the deal is only intended to solve the Iran issue for ten or so years. Some add that the United States will be no worse off then as it is now. However, pushing the problem to future generations of decision makers poses a moral problem and is also risky, as the case of North Korea showed in 2002 and 2003. The President may not have favorable options to stop Iran from building nuclear weapons 10 to 15 years from now. It is probably better to deal with the problem now and find a sustainable solution rather than a temporary one, which is what this deal ultimately represents. For some that means that the deal should be opposed and that is legitimate. For others, and hopefully the opponents as well, it means finding non-military ways to ensure that Iran does not create a dangerous nuclear capability in the future.

Iran certainly does not need centrifuge capabilities. Its uranium enrichment plans are unnecessary and uneconomic. The JCPOA creates a guaranteed path for Iran to buy nuclear power and research reactors and all the enriched uranium needed to fuel these reactors for their lifetimes. That enriched uranium would be far less costly than what Iran could hope to make domestically.

**Recommendations.** While recognizing more is needed, we believe it is incumbent to find ways to dissuade Iran from implementing nuclear enrichment plans that will create a great deal of instability and possibly lead to war. To that end, the United States should declare that any

production of separated plutonium or uranium enriched over five percent, whenever it occurs, is inconsistent with the intent of the JCPOA. It should also make clear that U.S. policy opposes Iran creating a semi-commercial enrichment program on the grounds of it being unnecessary, uneconomic, a proliferation risk, and a threat to U.S., regional, and international security.

The ending of the supplementary inspection provisions and the controls implicit in the procurement channel should be seen as a serious weakness of the agreement and efforts should be launched to ensure their continuation well into the future. The United States should state its intention to seek extensions of these important provisions or equivalent ones.

## Breakout Timelines: Technical Assessments

For many years we have calculated breakout timelines in collaboration with centrifuge experts at the University of Virginia. Our understanding from U.S. officials is that the U.S. methods and ours are similar in outcome. For example, our breakout results are similar to those of the U.S. administration when considering the centrifuge limits Iran has accepted during the first ten years of the JCPOA. In the case of about 6,000 IR-1 centrifuges, a stock of 300 kilograms of 3.5 percent LEU hexafluoride, and no available near 20 percent LEU hexafluoride, our breakout estimate would have a mean of about 12-14 months, where the minimum breakout time would be 11-12 months.[6] We have used the mean as the best indicator of breakout time and interpret the minimum time as a worst case. Thus, our estimate of breakout would confirm the United States' assessment that these specific limitations satisfy a 12-month breakout criterion.

### Iran's Stock of Near 20 Percent LEU

We have frequently expressed our concerns that Iran's retention of a stock of near 20 percent LEU could unacceptably lower breakout timelines.[7] Breakout estimates depend critically on Iran's usable stock of near 20 percent LEU. Thus, it is significant that the JCPOA requires Iran to get rid of the bulk of its remaining stock of near 20 percent LEU prior to Implementation Day, retaining only that in fuel elements for the Tehran Research Reactor (TRR). At the time of the April 2015 Lausanne framework agreement, the United States was willing to accept a larger inventory of near 20 percent LEU as long as it was mixed with aluminum, a step in preparing TRR fuel. However, there was significant disagreement with this position, including among U.S. partners. They assessed that the near 20 percent LEU could be recovered and reconverted relatively rapidly into LEU hexafluoride usable in a breakout. The latter position largely prevailed and a compromise in the JCPOA was reached, whereby Iran must get rid of most of its near 20 percent LEU. After Implementation Day, Iran is expected to possess only near 20 percent LEU that is in TRR fuel. This amount is estimated to be 60-80 kilograms, with about a third in irradiated TRR fuel and very difficult for Iran to recover in a timely manner. The fresh

[6] More recent ISIS calculations assume a more efficient average arrangement of the cascades and result in somewhat shorter estimates for this specific case compared to ones we have published earlier. This reflects a view that Iran may keep under a deal its most efficient cascades.

[7] For additional detail and sources see David Albright and Serena Kelleher-Vergantini, "The U.S. Fact Sheet's Missing Part: Iran's Near 20 Percent LEU, (Updated June 5, 2015 with new IAEA data)," ISIS Report, June 5, 2015. http://isis-online.org/uploads/isis-reports/documents/LEU_20_percent_update_June_5_2015_Final.pdf

LEU in the fuel could be recovered more quickly for use in a breakout but over the next few years, almost all of the LEU would be expected to be irradiated in the TRR.

**Recommendation.** Implementation Day, or the day when major sanctions are lifted, should occur only in case Iran does not have any 20 percent outside of TRR fuel.

**Effect of Re-Deployed Centrifuges**

A major gain in the JCPOA is that Iran must dismantle its excess centrifuges and place them in monitored storage. Earlier, one plan had been to simply disconnect them and remove cascade piping, which was judged as likely to be inadequate with respect to meeting a 12-month breakout criteria. Although centrifuge dismantlement is a far better option with respect to the breakout criteria, reinstallation of these same centrifuges is possible and will lower breakout timelines, albeit not as much as the case of removing only the piping.

According to the JCPOA, Iran will remove all excess centrifuges, in particular its IR-1 and IR-2m centrifuges, the latter being Iran's most advanced deployed centrifuge. However, at the Natanz Fuel Enrichment Plant, Iran is not removing all the associated equipment. At this plant, according to the JCPOA, Iran will remove "$UF_6$ pipework including sub headers, valves and pressure transducers at cascade level, and frequency inverters, and $UF_6$ withdrawal equipment from one of the withdrawal stations, which is currently not in service, including its vacuum pumps and chemical traps." The agreement does not appear to require the full dismantlement of all feed and withdrawal equipment used in the cascades at the Fuel Enrichment Plant. Leaving this equipment in the Natanz plant provides Iran a head start on re-starting enrichment in re-installed cascades.

The removal of excess centrifuges and associated cascade equipment at the Fordow Fuel Enrichment Plant is more thorough. With regards to excess centrifuge cascades, which total about half of those at the plant and are in the second hall of the Fordow plant, Iran must "remove all excess centrifuges and uranium enrichment related infrastructure. This will include removal of **all** centrifuges and UF6 pipework, including sub headers, valves and pressure gauges and transducers, and frequency inverters and converters, and UF6 **feed and withdrawal stations (emphasis added)."**

The excess centrifuges and associated equipment will be stored in Hall B of the Natanz FEP under IAEA monitoring. In case Iran decided to reinstall them at the FEP or elsewhere, the inspectors would learn of the diversion, although confirmation could be delayed if Iran blocks access to the inspectors and turns off any remote monitoring equipment.

If Iran were to break out, it would be expected to re-install centrifuges to lower breakout timelines. Estimating the resulting breakout timelines depend critically on assumptions about issues that are very difficult to know precisely. How much equipment will remain in the centrifuge plants, and how quickly could Iran re-install the centrifuges and associated equipment? Can Iran start enriching in these newly installed cascades rapidly, or are there additional delays before enrichment could resume in them, which lengthen breakout? Can Iran

successfully re-deploy its roughly 1,200 IR-2m centrifuges within about three months of starting a breakout, despite not having operated any of these cascades previously in the Natanz Fuel Enrichment Plant? Will actions still be taken to make reinstallation more difficult?

A key variable in these estimates is the rate that Iran could re-install centrifuges. Secretary of Energy Ernest Moniz stated in Senate testimony before the Senate Foreign Relations Committee that it would take Iran two to three years to reinstall all its dismantled equipment. This corresponds to an average rate of about two to over three cascades per month. Another estimate, which is used by another member of the E3+3, is that Iran could install no more than two cascades per month. In this analysis we have settled on a reinstallation rate of two cascades per month. In addition, we assume that enrichment in these two cascades does not start until the month following installation.

**IR-1 Centrifuges Only Re-installed.** If only IR-1 centrifuges were re-installed at a rate of two cascades per month, the breakout timeline would decrease to approximately 9-10 months. In this estimate, during ten months, Iran would install 20 cascades that contain about 3,500 centrifuges. This estimate assumes that failed centrifuges are replaced promptly. Breakage rates of the IR-1 machines can reach twenty, even thirty, percent per year, but Iran is well practiced in replacing these machines in cascades.

One implication of this high breakage rate is that as the years go by, Iran's stock of excess IR-1 centrifuges will decrease if it continues to enrich in the roughly 5,060 IR-1 centrifuges at the Natanz FEP. After five years, about 2,500-5,000 IR-1 centrifuges would be expected to have crashed and required replacement from the approximately 10,500 IR-1 centrifuges declared excess and stored in Hall B. At this point in time, Iran would have about 5,500-8,000 IR-1 centrifuges left in storage. This inventory remains sufficient for breakout under the above assumptions, which in our estimate discussed above involves the installation of about 3,500 IR-1 centrifuges over ten months. At the end of year eight, however, the inventory would be about 2,500-6,500 IR-1 centrifuges. After ten years, the inventory would drop to approximately 500-5,500 IR-1 centrifuges.[8] At this time, it may not have enough IR-1 centrifuges to breakout. So, as can be seen, if Iran enriches in its IR-1 centrifuges at the FEP, it could reach a point where it does not have enough IR-1 centrifuges on hand to aid in a breakout. However, this effect is offset after year 10 by the ability of Iran to start making advanced centrifuges again.

**IR-2m and IR-1 Centrifuges Re-installed.** Unlike the case of the IR-1 centrifuges, the reinstallation of IR-2m centrifuges can significantly affect breakout timelines. Our calculated result is that the breakout timeline drops to somewhat over seven months, when IR-2m centrifuges are reinstalled first. For the purposes of this discussion, a reinstallation rate of two cascades per month is used, where Iran first reinstalls IR-2m centrifuge cascades and afterwards re-installs IR-1 centrifuge cascades. This corresponds to an assumption that in a breakout Iran would deploy its most advanced machines first. Although it has not operated any of the six installed IR-2m cascades at the Fuel Enrichment Plant, Iran has for several years been

[8] The number of excess IR-1 centrifuges is projected in this estimate to have a lower bound of zero. However, once Iran's stock of excess IR-1 centrifuges falls to 500 or below, it can restart manufacturing these centrifuges but the stock cannot exceed 500 of them.

operating a single cascade at the Natanz Pilot Fuel Enrichment Plant. Given this prior experience and its decision to install over 1,000 IR-2m centrifuges at the Fuel Enrichment Plant and prepare for the installation of another 2,000 of them, we judge Iran would re-deploy IR-2m centrifuges first, despite the risks. The reward would be a considerably faster breakout.

It should be noted, however, the IR-2m centrifuges have experienced breakage rates at the Natanz pilot plant of about 20 percent, according to senior former officials close to the IAEA. This rate is much greater than expected and is believed to be related to difficulties in manufacturing or assembling this centrifuge adequately. To account for the need for spares, in this scenario only 1,100 out of 1,200 IR-2m centrifuges are deployed. The other 100 machines are held in reserve to replace broken ones during the period of the breakout. Iran may very well have more IR-2m centrifuges already manufactured, which could also be a source of spares and available to increase the number of IR-2m cascades contributing to the production of weapon-grade uranium in a breakout (see also below).

Another assumption is that the enrichment output of the IR-2m centrifuge while operating in cascade will be about four separative work units (swu) per year. The known range is between three and five swu per year. Energy Department officials have used five swu per year, as an upper bound on enrichment output.

The U.S. administration has stated its view that the IR-2m centrifuges would not be deployed in a breakout, citing the difficulties the IR-2m centrifuges have experienced at the Natanz Pilot Fuel Enrichment Plant. In essence, U.S. experts assume that the existing inventory of IR-2m centrifuges already manufactured and deployed, about 1,200 in number, are not reliable enough for use in a breakout.

However, this assumption can be challenged. The bulk of these centrifuges, about 1,008, are in six cascades at the Natanz Fuel Enrichment Plant and have not operated, so their quality is not known with assurance. Iran did intend to operate them and was installing the infrastructure to operate a total of about 3,000 IR-2m centrifuges at Natanz. So, while a relatively high breakage rate for these centrifuges is established, Iran intended to operate large numbers of them in production-scale cascades, if the Joint Plan of Action had not taken effect. Prudent planning would lead to assuming that Iran would use the IR-2m centrifuges, unless it is established with high confidence that these centrifuges cannot be used. Such high assurance does not seem to have been established.

**Breakout Timelines**

In our evaluations, a decrease in breakout time to 9-10 months, given all the uncertainties, would not be that significant. Thus, the reduction in breakout times from the re-installation of the IR-1 centrifuges falls within an acceptable range. However, a decrease to seven months, as the case with re-installed IR-2m centrifuges, is significant and appears to contradict claims that Iran would need 12 months to break out under limitations stated in the JCPOA.

**Recommendations.** We can understand both views on the question of the re-installation of the IR-2m centrifuges. But their reinstallation would lead to breakout times significantly below twelve months. As a result, the United States should seek to ensure that the IR-2m centrifuges cannot be re-installed. This can happen by establishing greater assurance in the poor operability of the existing IR-2m centrifuges, which may not be possible, or by establishing additional steps that would make their re-installation more time consuming. On the latter point, the United States should initiate a discussion with the Iranians to seek that IR-2m centrifuges are dismantled in a manner to ensure that they are more difficult, if not impossible, to redeploy quickly in a breakout. One potential way to do that is not to store the rotor assembly intact. Instead, the rotor assembly could be dismantled, for example by disconnecting the rotor tubes from the bellows and endcaps. Other alternatives should also be explored.

**Number of IR-2m Centrifuges**

An additional uncertainty is how many IR-2m centrifuges Iran has produced. Some experts have speculated that Iran has made up to 3,000 IR-2m centrifuges by now. Installation of additional IR-2m centrifuges would further reduce breakout timelines. The answer may be clearer once Iran declares its existing inventory of rotor tubes and bellows under the JCPOA.

**Recommendation.** If Iran declares a stock significantly larger than 1,200 IR-2m centrifuges, or a set of components in quantities for far more centrifuges, the United States should ensure that these centrifuges cannot be deployed quickly in a breakout.

Whatever the declaration, questions about these numbers may persist after the declaration. The JCPOA's verification arrangements on Iran's centrifuge numbers do not appear sufficient to determine if Iran has hidden away a large number of centrifuges. The JCPOA does not contain a provision that ensures that the IAEA can verify the number of centrifuges Iran has manufactured. Under the JCPOA, the IAEA is allowed to verify Iran's declared inventory of existing rotor tubes and bellows by item counting and numbering. These conditions are not sufficient to determine whether the declaration of the number of rotor tubes and bellows is complete (and therefore whether it may secretly possess hidden centrifuges). Iran does not appear obligated to provide to the IAEA additional needed information, such as the amount and type of raw materials and equipment procured historically for its centrifuge program that would allow a verification that Iran has fully declared its inventory of rotors and bellows and is not hiding a significant number of them, or by implication, centrifuges.

In determining a broader inventory of centrifuge rotor tubes and bellows produced in Iran, a value lies in records and evidence from procurement information related to goods Iran obtained from abroad over the years that needed to make those centrifuge parts. In several cases, it procured goods used in those parts only from abroad, such as in the case of high quality raw materials, such as maraging steel and carbon fiber. If Iran had to declare all its imports of key goods for its centrifuge program, or at least the ones relevant to the manufacture of rotor tubes and bellows, the IAEA can check with the supplier and member state to verify the amounts sent to Iran and can also ask about other possible procurements.

Once the IAEA can determine an inventory of key imported goods, it can recreate Iran's supply chain for centrifuge manufacturing and estimate whether Iran's declaration of centrifuge rotors and bellows (along with other components) is complete. Without obtaining Iran's declaration of key procurements, checking its declaration of centrifuge rotors and bellows will depend on existing member state information and their cooperation, which in the case of several key suppliers will likely not be forthcoming. Moreover, because Iran has conducted such extensive illegal, secret procurements for its centrifuge program, the member state information is incomplete and likely insufficient for the IAEA to verify or challenge Iran's declaration of centrifuge rotor tubes and bellows.

**Recommendations.** Despite the weakness of the centrifuge declaration provision in the JCPOA, the IAEA should use its authorities under the Additional Protocol to press Iran for procurement information relevant to rotors and bellows. In particular, it can argue that it needs this information to ensure that Iran does not have covert centrifuge plants enriching uranium. The United States, backed by Congress, should insist that the IAEA do so.

## Breakout Estimates in Years 10-13 and afterwards

There is a dearth of official public information about the numbers and types of centrifuges the agreement allows Iran to install from years 10 through 13. According to several negotiators, Iran's centrifuge capability, comprised of a mix of advanced centrifuges, will build up after year 10 and reach a breakout timeline of approximately six months by year 13. We are unaware of the uncertainties in this estimate. For example, would it be shorter, if re-installation factors were more fully considered?

Our understanding is that after year ten, Iran plans to first install mainly IR-2m and/or IR-4 centrifuges. Iran does not plan to install any additional IR-1 centrifuges. The fate of the IR-4 centrifuge is highly uncertain. This centrifuge, which features a carbon fiber bellows, has worked extremely poorly and may not be deployed in the end, although Iran plans to continue developing it under the JCPOA.

The agreed upon plan reportedly allows for an installation of up to 2,500-3,500 of IR-2m and IR-4 centrifuges, where the actual number and type will depend on their enrichment output, which remains uncertain. In that case, a lower enrichment output per centrifuge would allow a greater number of centrifuges. With this assumption, assuming that each of these centrifuges achieves a somewhat higher average output than now, or 4-5 swu/year, this range of centrifuges would correspond to a total production of roughly 12,500-14,000 swu per year.[9]

Iran would also be able to install some IR-6 or IR-8 centrifuges during this initial period, but the numbers would be relatively small. Moreover, Iran views the IR-6 centrifuge as a step toward the IR-8 centrifuge, so Iran would favor the deployment of the IR-8 over the IR-6 centrifuge. Starting in year 11, according to negotiators, Iran could install a complete cascade of IR-8 centrifuges but this cascade would be expected to have less than the 164-174 centrifuges in an

[9] In this case, for example, the lower value of 12,500 swu per year is the result of multiplying 3,500 and 4 swu/year and the upper bound is the result of multiplying 2,500 and 5 swu/year.

IR-1 cascade, due to the much greater enrichment output of the IR-8 compared to the IR-1 centrifuge. According to Secretary of Energy Ernest Moniz in testimony before the Senate Foreign Relations Committee on July 24, 2015, the IR-6 has an estimated enrichment output of about 7-8 times that of the IR-1 centrifuge. Assuming that each IR-1 has an enrichment output in cascade of 0.9 swu per year, this value means that the IR-6 centrifuge has an estimated 6-7 swu per year (in cascade). The IR-8 has an estimated enrichment output about 15-16 times greater than the IR-1 centrifuge, or 13-14 swu per year (in cascade). One cascade of IR-8 centrifuges, containing on order of 100 centrifuges, would have a total capacity of 1,350 swu per year.

Combining these capacities, in total, Iran in year 13 would have a total estimated enrichment output of about 13,850-15,350, rounded to 14,000 to 15,000 swu per year. With a total stock of 300 kg of 3.5 percent LEU and no near 20 percent LEU, this capacity corresponds to a breakout of roughly six months, matching the six month breakout time stated above as the goal at year 13.

After year 10, under the JCPOA, Iran is allowed to build 200 IR-8 centrifuges per year. These machines could be installed later, after year 13. In five years, under the JCPOA, Iran could make 1,000 IR-8 centrifuges, for a total capacity of about 13,000-14,000 swu per year by the end of year 15. It could further expand its enrichment capacity by also installing IR-2m, IR-4, and IR-6 centrifuges. Its two main centrifuge manufacturing sites, one near Karaj and the other near Esfahan, which were being built when the JPA went into effect in the fall of 2013, are designed to make thousands of centrifuges per year. These plants could be outfitted with equipment and raw materials more easily after year 10. At this time, the tight control on imports offered by the procurement channel ends. This anticipated increase in centrifuge manufacturing capability coincides after year 13 with the unwinding of the major centrifuge limitations.

At year 15, Iran could have a total installed capacity of at least 27,000-29,000 swu per year, where we ignore any additional capacity increase as a result of the installation of more IR-2m, IR-4, or IR-6 centrifuges. With 300 kg of 3.5 percent LEU and no near 20 percent LEU, the breakout time is estimated to be approximately 3 months. But after year 15, Iran is no longer limited in the amount of LEU it can accumulate, which would lower this breakout time dramatically in year 16. With the same enrichment capacity, the breakout time would drop by about almost one half to between 1.5 to 2 months, as Iran accumulates more than 1,500 kg of 3.5 percent LEU within the first several months of year 16. See table 1 and figure 1.

After year 15, Iran can resume production of near 20 percent LEU and it has told negotiators it intends to do so. How quickly it would produce near 20 percent LEU is not known, but with such a large installed capacity, it would not take long to accumulate a relatively large inventory. With a capacity factor of approximately 30,000 swu per year, and about 250 kg of near 20 percent LEU hexafluoride, breakout times would drop to less than a month, really to less than two weeks.

With the resumed production of near 20 percent LEU and Iran's ability to install hundreds, perhaps thousands, of advanced centrifuges per year, Iran can lower breakout time much more.

Within a few years and under a variety of scenarios, Iran could deploy sufficient advanced centrifuges, accumulate enough near 20 percent LEU, and be skilled enough to lower breakout estimates to a few days.

At this point, breakout with enough weapon-grade uranium for one, two, or three nuclear weapons could occur without the IAEA being aware it happened until after the fact. Delaying inspector access, or turning off any remote monitoring that remains, is straightforward and the world is unlikely to react in the week or so needed by Iran to finish its task.

With so much capacity, overt breakout becomes a real threat. However, the development of covert enrichment plants becomes a much more severe threat as Iran greatly expands its centrifuge capabilities. This problem is aggravated since several key inspection provisions will also end after year 15, including the access provision that mandates the snapback of sanctions if Iran denies access for more than 24 days.

With Iran being able to move rapidly toward nuclear weapons, either overtly or covertly, the threat of military strikes appears a hollow option. However, there is nothing in the JCPOA that mandates Iran to build up an uneconomical, dangerous domestic enrichment program. Dissuading, even preventing, Iran from reaching this level of capability must be a priority, regardless of one's position on the JCPOA.

## Major Recommendations

To recap, the following are the major recommendations from the above text:

The United States should ensure, via additional discussions with Iran, that IR-2m centrifuges are dismantled in a manner to ensure that they are more difficult, if not impossible, to redeploy quickly in a breakout. This can happen by establishing greater assurance in the poor operability of the existing IR-2m centrifuges, which may not be possible, or by establishing additional steps that would make their re-installation more time consuming. On the latter point, the United States should initiate a discussion with the Iranians to seek that IR-2m centrifuges are dismantled in a manner to ensure that they are more difficult, if not impossible, to redeploy quickly in a breakout. One potential way to do that is not to store the rotor assembly intact. Instead, the rotor assembly could be dismantled, for example by disconnecting the rotor tubes from the bellows and endcaps. Other alternatives should also be explored.

We believe it is incumbent to find ways to dissuade Iran from implementing nuclear enrichment plans that will create a great deal of instability and possibly lead to war. To that end, the United States should declare that any production of separated plutonium or uranium enriched over five percent, whenever it occurs, is inconsistent with the intent of the JCPOA. It should also make clear that U.S. policy opposes Iran creating a semi-commercial enrichment program on the grounds of it being unnecessary, uneconomic, a proliferation risk, and a threat to U.S., regional, and international security.

The ending of the supplementary inspection provisions after year 15 and the controls embodied in the procurement channel, should be seen as a serious weakness of the agreement and efforts should be launched to ensure their continuation well into the future. The United States should state its intention to seek extensions of these important provisions or equivalent ones.

Implementation Day, or the day when major sanctions are lifted, should occur only in case Iran does not have any 20 percent outside of TRR fuel.

If Iran declares a stock significantly larger than 1,200 IR-2m centrifuges, or a set of components in quantities for far more centrifuges, the United States should ensure that these centrifuges cannot be deployed quickly in a breakout.

Despite the weakness of the centrifuge declaration provision in the JCPOA, the IAEA should use its authorities under the Additional Protocol to press Iran for procurement information relevant to rotors and bellows. In particular, it can argue that it needs this information to ensure that Iran does not have covert centrifuge plants enriching uranium. The United States should insist that the IAEA do so.