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Iran's Rapid Enrichment Progress Moves It Ever Closer to a Nuclear Weapons Capability: Centrifuge Enrichment and the IAEA May 25, 2012 Safeguards Update

In various papers since 2008, this author has outlined how Iran's growing centrifuge enrichment program could provide it with the ability to produce Highly Enriched Uranium (HEU) for nuclear weapons.[2] On May 25, 2012 the International Atomic Energy Agency (IAEA) published its latest safeguards update. This update shows that not only has Iran's centrifuge enrichment effort continued to be unimpeded by Western counteraction but that it has undergone a significant expansion. In particular in the last six months Iran has increased its production of 3.5% enriched uranium at the FEP at Natanz by about 60% and has installed over 1,000 new centrifuges at the well-protected Fordow facility. Together these increases mean that Iran has increased its total enrichment capacity by nearly 80% since just last fall and tripled it since 2009 (See Appendix 1, Table 1). This reality is in contrast to the continuing myth that cyberattacks against Iran's centrifuge enrichment facilities led to significant reductions in Iran's enriched uranium production.[3]

Though media coverage of this latest IAEA safeguards update has focused on the discovery of 27% enriched uranium particles at one of Iran's enrichment facilities, the rapid increase in Iran's overall enrichment capacity is the real story.[4] The rapid expansion of Iran's enrichment capacity continues to shorten the time that Iran would require to produce the HEU needed to manufacture a nuclear weapon. I currently estimate that Iran could produce enough HEU for a nuclear weapon in one to three months and might be able to produce enough HEU for three nuclear weapons in just six months if it were to decide to quickly do so (See Appendix 1).

In order to produce a nuclear weapon Iran would also have to manufacture the non-nuclear components for such a weapon. Iran has already made substantial progress in this area, in part aided by a Russian nuclear weapon expert. I have estimated that Iran could produce these required non-nuclear components in just two to six months should it decide to quickly do so.[5]

However, this does not mean that I think Iran will become an overt nuclear weapon state in the near future. As I stated last September:

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[1] The author has multiple affiliations. This paper was produced for the Nonproliferation Policy Education Center. 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 RAND bears no responsibility for any of the analysis and views expressed in it.

[2] My most recent report is: Gregory S. Jones, "Facing the Reality of Iran as a De Facto Nuclear State: Centrifuge Enrichment and the IAEA's February 24, 2012 Safeguards Update," March 22, 2012, http://www.npolicy.org/article.php?aid=1166&tid=4

[3] David E. Sanger, "Obama Order Sped Up Wave of Cyberattacks Against Iran," *New York Times*, June 1, 2012.

[4] The 27% enriched uranium particles are probably the result of transients during startup operations and are not necessarily indicative of sustained production of 27% enriched uranium.

[5] Gregory S. Jones, "Iran's Efforts to Develop Nuclear Weapons Explicated, Centrifuge Uranium Enrichment Continues Unimpeded, The IAEA's November 8, 2011 Safeguards Update," December, 6, 2011, pp.10-13, http://npolicy.org/article.php?aid=1124&rid=4

> That is not to say that I expect Iran to divert nuclear material from IAEA safeguards anytime soon. After all, why should it? It can continue to move ever closer to the HEU required for a nuclear weapon with the blessing of the IAEA. Iran would only need to divert nuclear material from safeguards when it would want to test or use a nuclear weapon. Recall that the U.S. was unable to certify that Pakistan did not have nuclear weapons in 1990, but it was only in 1998 that it actually tested a bomb. Similarly, though it could be many years before Iran becomes an overt nuclear power, it needs to be treated as a de facto nuclear power simply by virtue of being so close to having a weapon.[6]

Most analysts (including those in the U.S. Government) have yet to accept the view that Iran is a de facto nuclear weapon state. They still hope that a combination of negotiations and sanctions might prevent Iran from acquiring nuclear weapons. Many have suggested that the basic focus of the P5+1 negotiating effort should be to get Iran to stop enriching uranium to 20% and to export its stockpile of this material but that Iran should otherwise be allowed to keep its enrichment program and be allowed to continue to enrich uranium to levels less than 5%.[7] As I have pointed out previously, such a position would legitimize Iran's centrifuge enrichment program and permit Iran to expand it.[8] This expanded program would provide Iran rapid access to the HEU needed for a nuclear weapon. Even now Iran can produce enough HEU for a nuclear weapon in less than four months starting from only 3.5% enriched uranium (see Appendix 2). A substantially expanded enrichment program which was limited to producing less than 5% enriched uranium could still produce the HEU required for a nuclear weapon in just a few weeks. The only reasonable negotiated outcome that will make it difficult for Iran to quickly produce nuclear weapons is for Iran to give up its entire enrichment program and all of its enriched uranium stockpiles.

At any rate it now seems unlikely that negotiations will be able to get Iran to give up even its 20% enrichment capacity and stockpile. The latest negotiating sessions of May 23 and 24 were generally seen as failures. On May 27, Fereydoon Abbasi, the head of Iran's Atomic Energy Organization said "We have no reason to retreat from producing the 20 percent because we need 20 percent uranium just as much to meet our needs."[9]

An examination of the latest IAEA safeguards update shows that Iran has been taking steps to lay the groundwork for this position. Though at the beginning of 2012 Iran increased its 20% enriched uranium production from about 3 kilograms per month to about 9 kilograms a month, Iran's 20% enriched uranium stockpile only grew by one kilogram (from 67 kilograms to 68 kilograms) during the period February to May 2012. This small increase is the result of Iran using 29 kilograms of this material to manufacture fuel for the Tehran Research Reactor (TRR). In the short run this is a favorable development since the smaller Iran's stockpile of 20% enriched uranium, the longer it will take Iran to produce the HEU for a nuclear weapon.

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[6] Gregory S. Jones, "No More Hypotheticals: Iran Already Is a Nuclear State, *The New Republic*, September 9, 2011, http://www.tnr.com/article/environment-and-energy/94715/jones-nuclear-iran-ahmadinejad

[7] The P5+1 are the United States, United Kingdom, France, Russia, China and Germany.

[8] Gregory S. Jones, "Facing the Reality of Iran as a De Facto Nuclear State: Centrifuge Enrichment and the IAEA's February 24, 2012 Safeguards Update," March 22, 2012, p.9, http://www.npolicy.org/article.php?aid=1166&tid=4

[9] Thomas Erdbrink, "After Talks Falter, Iran Says It Won't Halt Uranium Work," *The New York Times*, May 27, 2012.

However, in the long run, if such activity provides the justification for Iran to keep producing 20% enriched uranium, Iran will be able to amass a large stockpile of 20% enriched uranium which would allow Iran to be able to quickly produce the HEU for a nuclear weapon. Iran will soon have little need to keep producing fuel for the TRR since the entire core of the TRR contains about 32 kilograms of 20% enriched uranium and once replaced, the reactor will only consume about 7 kilograms of 20% enriched uranium per year[10] yet Iran is producing about 9 kilograms of 20% enriched uranium per month.

Iran's inflexible position on uranium enrichment gives the lie to the notion that sanctions are having a crippling effect on Iran. The latest round of sanctions is designed to significantly affect Iran's overall economy by making it more and more difficult for Iran to export its oil. However, these sanctions are not authorized by the United Nations but rather imposed unilaterally by the U.S. and the EU. Despite the IAEA's revelations last November of Iran's efforts to develop the non-nuclear components for a nuclear weapon, both Russia and China have refused to support any additional UN sanctions against Iran. Indeed both countries have continued trading with Iran and China continues to purchase oil from Iran.

Nor are China and Russia the only countries that have not adopted these sanctions. India, with its important economy, has actually increased its purchases of Iranian oil. India has gone so far as to change its tax code so as to facilitate a method of payment that involves using rupees rather than dollars. On May 31 Indian Foreign Minister S.M. Krishna reiterated that Iran remained a key energy supplier of India and that U.S. sanctions would not be allowed to impact "legitimate trade interests" between Iran and India.[11] With such an attitude by non-Western countries, it is hardly surprising that U.S. and EU sanctions have not had the necessary bite to compel Iran to give up its uranium enrichment program.

If negotiations and sanctions cannot stop Iran from acquiring nuclear weapons, military action is the only remaining option. The possibility of an Israeli military strike to "take out" Iran's enrichment facilities has been much in the news lately. Though not explicit, there seems to be a general view that this would be a one-time strike, similar to the ones that Israel carried out on nuclear reactors in Iraq in 1981 and in Syria in 2007. Concerns have been raised about the progress of the Iranian program and whether with its partial move of its centrifuge enrichment activities to the underground site near Qom, Iran may be entering a "zone of immunity" whereby the Iranian centrifuge enrichment program can no longer be successfully attacked in a single strike.

One unstated assumption that is at the heart of almost every discussion of an Israeli strike on Iran is that such an attack would be very effective. Indeed most discussions seem to assume that an attack would completely destroy most if not all of Iran's centrifuges and eliminate its enriched uranium stockpile as well. In fact, attacking centrifuge enrichment facilities is quite different from attacking single nuclear reactors and Iran's enrichment program is already well into a zone of immunity with regard to a single air strike. At its main enrichment facility at Natanz, Iran has

[10] Gregory S. Jones, "Fueling the Tehran Research Reactor: Technical Considerations on the Risks and Benefits," October 12, 2009, http://www.npolicy.org/article.php?aid=124&rt=&key=gregory%20Jones&sec=article&author=

[11] "India snubs US sanctions on Tehran," *Times of India*, June 1, 2012.

somewhere between 45 and 52 cascades operating in parallel.[12] An air strike on Natanz that scored multiple bomb hits would shut down the entire facility. But the majority of the cascades would be undamaged and not able to operate only due to damage to piping and the loss of utilities. It would only take a few months of repairs before these undamaged cascades were back in operation. Even for the cascades that suffered bomb hits, the majority of the centrifuges would still be undamaged. Iran could pull out the undamaged centrifuges and use them to build new cascades. It would only take four to six months before Iran would have returned to close to full production.

A further problem is Iran's current stockpiles of about 3,300 kilograms of 3.5% enriched uranium and 68 kilograms of 19.7% enriched uranium. These stockpiles represent years of centrifuge plant operation but would be very difficult to destroy by air attack. The combined volume of these two stockpiles is less than one cubic yard—making them very easy to hide or protect.

Certainly the Israelis must be aware of the limitations of a single strike against Iran's nuclear facilities. No doubt this is one reason why Israel has not struck Iran already. Though the Israelis may find strike threats useful in order to put pressure on Iran, one must be concerned that by emphasizing this option, Israel's government may have painted itself into a corner. Israel may feel compelled for internal political reasons to eventually carry out such an attack even though Israel's government is aware that such an attack will be ineffective.

President Obama and more recently Defense Secretary Leon Panetta have pledged to take any action necessary to prevent Iran from obtaining nuclear weapons.[13] Fulfilling such a pledge militarily would require at a minimum a prolonged bombing campaign against Iran's nuclear sites. There are two problems with such a bombing campaign. First, Iran could respond by dispersing its centrifuges. Indeed, centrifuge enrichment with its many parallel cascades would be ideal for such dispersal. The U.S. would be able to find and bomb some of these dispersed enrichment sites but many would continue in operation undetected. Second, such a prolonged bombing campaign would run a serious risk of turning into a large-scale war with Iran. Though no doubt the U.S. would eventually win such a war, I think that given the financially-exhausted and war-weary condition of the U.S., such a war would be ill-advised. In any case a situation where the U.S. faces the choice between accepting Iran as a nuclear weapon state or needing to go to war to prevent it must be considered a policy failure.

Non-Proliferation After Iran

If in fact Iran is already a de facto nuclear weapon state, where should the U.S. go from here with regards to its non-proliferation policy? The key will be to learn from our failure with Iran and prevent additional countries from acquiring nuclear weapons. This will require a two-prong approach.

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[12] Iran has declared to the IAEA that it has 52 cascades in operation but its enriched uranium production is only equivalent to about 45 cascades operating at full capacity.

[13] "Full Transcript: Defense Secretary Leon Panetta," ABC News, May 27, 2112, http://abcnews.go.com/Politics/full-transcript-defense-secretary-leon-panetta/story?id=16437246&page=7

First, as President Obama has indicated, Iran's de facto nuclear status will motivate a number of other countries to try to emulate Iran's success. The U.S. needs to take decisive action to head off these efforts on a country by country basis as soon as the first steps towards acquiring the fissile material for nuclear weapons are detected. Taking early action runs counter to normal government instincts, which is to try to "kick the can down the road" and avoid taking any unpleasant actions unless it has to. The lack of early action has been a hallmark of U.S. non-proliferation policy since the Reagan Administration and has facilitated Pakistan, India, North Korea and now Iran to acquire the fissile material required for nuclear weapons.

Yet as we saw with Libya, early action can be quite effective. Many believe that Gaddafi made a mistake by giving up a nuclear weapons program but the fact of the matter is that he had no choice. His effort was discovered early, before Libya had even begun to enrich uranium and Gaddafi had no other option.

Second, there needs to be a change to the IAEA's safeguards regime so as to prevent countries from acquiring the fissile material needed for nuclear weapons with the IAEA's approval. Some in the U.S. Congress have called for military action against Iran if it starts to enrich uranium to levels greater than 20%. But under current IAEA rules, Iranian enrichment to levels greater than 20% (including 90%, the level required for nuclear weapons) would be perfectly acceptable as long as Iran declared the activity to the IAEA.

Similarly, the IAEA permits non-nuclear weapon states to produce pure compounds of plutonium by reprocessing spent fuel. Informally, the IAEA does require that the country carrying out enrichment to levels greater than 20% or reprocessing activities provide some rationale as to how these activities are related to some peaceful nuclear activity but the rationale does not have to be very plausible. For example, a country can say that it is stockpiling the plutonium for use in a breeder reactor even if it is now more than 40 years since such reactors were first supposed to come into operation and that such reactors are still decades away. For example, Japan already has a plutonium stockpile of nearly 45 metric tons. About 35 metric tons is stored overseas but about 10 metric tons (enough to produce thousands of nuclear weapons) is stored in Japan.[14] Though in the aftermath of the Fukushima nuclear accident Japan's future use of nuclear power is in question, Japan's nuclear industry has announced plans to further increase its domestic stockpile of plutonium.[15]

Much of providing the proper rationale involves learning to play the game properly. Iran got itself into trouble by conducting clandestine nuclear activities prior to 2004. More recently Iran did a better job and explained that its production of 20% enriched uranium was required to produce research reactor fuel and it has begun to produce some research reactor fuel from its 20% enriched uranium stockpile. Iran's production of large amounts of 20% enriched uranium is generally agreed to be moving Iran close to the possession of the fissile material needed for a nuclear weapon, yet this production has not caused the IAEA to say that Iran is violating safeguards even though Iran is currently producing more 20% enriched uranium in one month than the research reactor uses in one year.

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[14] *Global Fissile Material Report 2011: Nuclear Weapon and Fissile Material Stockpiles and Production*, Sixth Annual report of the International Panel on Fissile Materials, January 2012, p.23.

[15] Eric Talmadge, "Japan to make more plutonium despite big stockpile," Associated Press, June 1, 2012.

The U.S. Government has recognized this problem and in its nuclear cooperation agreement with the United Arab Emirates, it requires the UAE not to possess facilities that can engage in uranium enrichment or the reprocessing of spent fuel which could produce plutonium, HEU or U-233 (another material that can be used to produce nuclear weapons). However, the U.S. administration has discovered the drawback to attempting to handle this problem through its bilateral nuclear cooperation agreements. In the face of competition from Russia and France, the U.S. has proposed nuclear cooperation agreements with Vietnam and Jordan that lack these provisions. Only if the issue is approached by the IAEA will there be uniform standards without commercial pressures undercutting non-proliferation.

Furthermore, even the standards for the UAE are not enough. Non-nuclear weapon countries must be prohibited from possessing any materials or facilities that can quickly provide fissile material for nuclear weapons. This includes prohibiting not only enrichment and reprocessing facilities but also separated HEU, plutonium or U-233 and HEU, plutonium or U-233 that is contained in unirradiated reactor fuel (such as HEU fuel for research reactors or mixed oxide fuel for power reactors).

The IAEA does not have the legal authority to prohibit countries from possessing such materials or facilities but it does have the responsibility to safeguard these materials and facilities. As I have discussed elsewhere,[16] IAEA safeguards are supposed to be more than just an accounting system but rather provide "timely warning" of diversion of nuclear materials. However, the IAEA cannot safeguard these facilities and materials in a timely warning sense. The IAEA needs to admit this fact and make clear that any such facilities and materials in non-nuclear weapon states are not being effectively safeguarded. This issue is significantly larger than just Iran and would include Japan, Germany, the Netherlands and Brazil at a minimum. It will be up to these countries to explain why they need to continue to possess these materials and facilities given that they cannot be effectively safeguarded. Given the state of nuclear power in a post-Fukushima world, plausible explanations may be difficult to conjure.

The U.S. needs to urge the IAEA to be clear about what materials and facilities it can effectively safeguard and which it cannot. At the same time the U.S. needs to take early action to ensure that any countries that attempt to follow Iran's successful path are prevented from gaining access to the fissile material required for nuclear weapons. Otherwise, the number of nuclear-armed countries will continue to grow until the catastrophe of nuclear use occurs. Just one nuclear weapon detonated in a city could kill hundreds of thousands—roughly 100 times as many people than were killed on 9/11.

[16] Gregory S. Jones, An In-Depth Examination of Iran's Centrifuge Enrichment Program and Its Efforts to Acquire Nuclear Weapons, August 9, 2011, pp. 16-23, http://npolicy.org/article.php?aid=1092&rid=4

Appendix 1

Detailed Analysis of the IAEA May 25, 2012 Safeguards Report and Methods Whereby Iran Could Produce HEU for Nuclear Weapons

Iranian Centrifuge Enrichment of Uranium

Iran has three known centrifuge enrichment facilities. Iran's main facility is the Fuel Enrichment Plant (FEP) at Natanz. The basic unit of Iran's centrifuge enrichment effort is a cascade which originally consisted of 164 centrifuges but Iran has now modified the majority of the cascades by increasing the number of centrifuges to 174. (All centrifuges installed up to now have been of the IR-1 type.) Each cascade is designed to enrich natural uranium to 3.5% enriched uranium. As of May 19, 2012, Iran had installed a total of 55 cascades, 31 of which each contain 174 centrifuges and the remaining 24 cascades each contain 164 centrifuges. This results in a total of 9,330 centrifuges. Of these 55 cascades, 52 (containing 8818 centrifuges) were declared by Iran as being fed with uranium hexafluoride and therefore were producing 3.5% enriched uranium though the IAEA has indicated that not all of these 8,818 centrifuges may be operational.[17]

Iran began producing 3.5% enriched uranium at the FEP in February 2007 and as of May 11, 2012 Iran had produced a total of 4,189 kilograms (in the form of 6,197 kilograms of uranium hexafluoride). Since 844 kilograms of this enriched uranium has already been processed into 19.7% enriched uranium (see the PFEP and FFEP below) and a further 21 kilograms was converted into uranium dioxide for use as fuel in the TRR, Iran's current stockpile of 3.5% enriched uranium is 3,324 kilograms. Iran's current production rate of 3.5% enriched uranium is about 158 kilograms per month.[18] This production rate represents about a 60% increase from 2011 when the production rate was about a steady 100 kilograms per month and represents about a tripling of the rate since 2009 (see Table 1). From the production rate of 3.5% enriched uranium, it is easy to calculate that the FEP has a separative capacity of about 6,900 separative work units (SWU) per year.[19]

Iran also has the Pilot Fuel Enrichment Plant (PFEP) at Natanz, which is used to test a number of more advanced centrifuge designs. These are usually configured as single centrifuges or small ten or twenty centrifuge test cascades. Since November 2011, Iran has installed a cascade of 164 IR-2m centrifuges and though this cascade appears ready to begin to produce enriched uranium, it has yet to do so. Iran has also installed 129 IR-4 centrifuges in a separate cascade but has also not yet started any enriched uranium production.

[17] "Not all of the centrifuges in the cascades that were being fed with UF_6 may have been working." *Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions in the Islamic Republic of Iran*, GOV/2012/23, May 25, 2012, p.4.
[18] To avoid problems with the fact that the length of a month is variable, we have adopted a uniform month length of 30.44 days.
[19] Assuming 0.4% tails. A Separative Work Unit is a measure of the amount of enrichment a facility can perform. The SWU needed to produce a given amount of enriched uranium product can be calculated if the U-235 concentration in the product, feed and tails are known.

Table 1
Average Iranian Production Rate of 3.5% Enriched Uranium
Late 2008 to Mid-2012

IAEA Reporting Interval	Average 3.5% Enriched Uranium Production Rate (Kilograms Uranium per Month)
11/17/08-1/31/09	52
2/1/09-5/31/09	53
6/1/09-7/31/09	57
8/1/09-10/31/09	57
11/22/09-1/29/10	78
1/30/10-5/1/10	81
5/2/10-8/6/10	80
8/7/10-10/17/10	95
10/18/10-2/5/11	88
2/6/11-5/14/11	105
5/15/11-8/13/11	99
8/14/11-11/1/11	97
11/2/11-2/4/12	115
2/5/12-5/11/12	158

In addition, there are two full cascades each with 164 IR-1 type centrifuges at the PFEP. These two cascades are interconnected and are being used to process 3.5% enriched uranium into 19.7% enriched uranium. In February 2010, Iran began producing 19.7% enriched uranium at the PFEP using one cascade. It added the second cascade in July 2010. As of May 18, 2012, Iran had produced 74.4 kilograms of 19.7% enriched uranium (in the form of 110.1 kilograms of uranium hexafluoride) at this facility. Iran's production rate of 19.7% enriched uranium at the PFEP has been fairly steady over the past year and is currently about 3.12 kilograms per month. The centrifuges at this facility are each producing about 0.9 SWU per year.

Finally, Iran has constructed an enrichment facility near Qom. Known as the Fordow Fuel Enrichment Plant (FFEP), Iran clandestinely started to construct this plant in violation of its IAEA safeguards. Iran only revealed the existence of this plant in September 2009, after Iran believed that the West had discovered the plant.

Iran has installed two sets of two interconnected cascades at the FFEP (each cascade contains 174 centrifuges, IR-1 type) in order to produce 19.7% enriched uranium from 3.5% enriched uranium as is being done at the PFEP. The first of these two sets began production on December 14, 2011 and the second set began operation on January 25, 2012. As of May 13, 2012, Iran had produced 24.0 kilograms of 19.7% enriched uranium (in the form of 35.5 kg of uranium hexafluoride) at this facility. This facility is currently producing 19.7% enriched uranium at the rate of 5.2 kilograms per month.

With the start of these two sets of interconnected cascades at the FFEP, Iran has made good on its announcement in June 2011 that it would triple its production rate of 19.7% enriched uranium. Currently Iran is producing a total of about 8.3 kilograms of 19.7% enriched uranium per month. As of mid-May, Iran had produced a total of about 98 kilograms of 19.7% enriched uranium. Since Iran has converted about 29 kilograms of this uranium into a uranium oxide compound for use as fuel in the TRR, and further blended down about 1 kilogram to lower enrichments, Iran's current stockpile of 19.7% enriched uranium is about 68 kilograms, which is only about 1 kilogram higher than it was at the time of the last IAEA update in February.

Iran has installed the piping and centrifuge casings for an additional 2088 centrifuges (12 cascades) at the FFEP. Since the last IAEA update in February, Iran has installed two complete cascades worth of centrifuges (174 centrifuges per cascade) and installed 20 centrifuges in a third cascade. These two additional cascades have yet to begin operation. The IAEA has asked Iran whether these new cascades are to be interconnected to produce yet more 19.7% enriched uranium or only 3.5% enriched uranium but Iran says that the installation of these new cascades is not yet complete and that it will only inform the IAEA prior to the start of their operation. This development opens the possibility that Iran could further increase its rate of 19.7% enriched uranium. With the two cascades already installed, Iran could put a fourth set of two interconnected cascades into operation at almost any time and increase its production of 19.7% enriched uranium to as much as 12.8 kilograms a month.[20] Given Iran's current rate of production rate of 3.5% enriched uranium at the FEP, Iran could run four additional sets of two interconnected cascades (beyond the two already in operation at the FFEP and the one in operation at the PFEP) to produce 19.7% enriched uranium without the need to drawdown its stockpile of 3.5% enriched uranium. If Iran were to construct and start to operate these four additional sets of cascades then its overall production rate of 19.7% enriched uranium could be as high as 22.4 kilograms per month.

Iranian Options for Producing HEU

Given that Iran currently has a total enrichment capacity of 8,100 SWU per year at the FEP, FFEP, and PFEP and stockpiles of about 3,300 kilograms of 3.5% enriched uranium and 68 kilograms of 19.7% enriched uranium, Iran has a number of options for producing the 20 kilograms of HEU required for a nuclear weapon.

The most straightforward method Iran could use to produce HEU would be batch recycling. In this process, no major modifications are made to Iran's enrichment facilities but rather enriched uranium is successively run though the various enrichment facilities in batches until the desired enrichment is achieved. In the past I have calculated that Iran could use a two-step process to produce HEU. In the first step, 3.5% enriched uranium would be enriched to 19.7% enriched uranium. Iran has already demonstrated this step by producing 19.7% enriched uranium at the PFEP and FFEP. In the second step, 19.7% enriched uranium would be enriched to 90% enriched uranium. My calculations for this second step rely on work by Glaser which demonstrated that by reducing the flow through the cascade, it was possible to achieve the production of 90% enriched uranium from 19.7% enriched uranium in one step without a

[20] Assuming 0.9 SWU per centrifuge-year.

significant loss of separative capacity.[21] This process is illustrated for Iran's current situation in Table 2.

Table 2

Time, Product and Feed Requirements for the Production of 20 kg of HEU by Batch Recycling at the FEP (6,900 SWU per year total) (The Second Step is Based on Glaser's Analysis)

Cycle	Product Enrichment and Quantity	Feed Enrichment and Quantity	Time for Cycle (Days)
First	19.7% 90.2 kg	3.5% 1,060 kg	23
Second	90.0% 20 kg	19.7% 153.2 kg*	8
Total			35**

* Includes 68 kilograms of 19.7% enriched uranium that Iran has already stockpiled.
**Includes four days to account for equilibrium and cascade fill time.

Two steps are required. In the first step, Iran needs to produce 158.2 kilograms of 19.7% enriched uranium (including 5 kilograms for the plant inventory in the second step). However, since it has already produced 68 kilograms of 19.7% enriched uranium, Iran needs only to produce an additional 90.2 kilograms. This step requires 1,060 kilograms of 3.5% enriched uranium as feed but Iran's current stockpile well exceeds this figure. In the second step, the 19.7% enriched uranium is further enriched to the 90% level suitable for a nuclear weapon. Using Iran's currently operating centrifuges at the FEP, the batch recycling would take about one month.

As was stated above, this calculation depends on Glaser's published calculations of the effectiveness of reduced cascade flow so that uranium can be enriched from 19.7% to 90% in one step. I am not the only analyst who has relied on Glaser's work, as both Levi[22] and the International Institute for Strategic Studies[23] have based their calculations on Glaser's calculations. However, as I wrote last fall, questions have been raised about the validity of Glaser's work and I have had to examine methods whereby Iran could produce the 20 kilograms of HEU required for a nuclear weapon without relying on Glaser's calculations.[24]

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[21] Alexander Glaser, "Characteristics of the Gas Centrifuge for Uranium Enrichment and Their Relevance for Nuclear Weapon Proliferation", *Science and Global Security*, Vol. 16, 2008. In particular see Table 3 on p.16.
[22] Michael A. Levi, "Drawing the Line on Iranian Enrichment," *Survival*, Vol. 53, No. 4, August-September 2011, pp.180-181.
[23] *Iran's Nuclear, Chemical and Biological Capabilities, A net assessment*, an IISS strategic dossier, The International Institute for Strategic Studies, London, February 2011, p.73.
[24] Gregory S. Jones, "Iran's Efforts to Develop Nuclear Weapons Explicated, Centrifuge Uranium Enrichment Continues Unimpeded, The IAEA's November 8, 2011 Safeguards Update," December, 6, 2011, p.5, http://npolicy.org/article.php?aid=1124&rid=4

Iran could still produce HEU by batch recycling at the FEP but the process would require three steps. Each pass would produce the feed required for the next cycle, which would include the plant inventory (in this case, 2 kilograms for each cycle). Iran would need to produce sufficient 19.7% enriched uranium from 3.5% enriched feed, then further enrich this 19.7% enriched uranium to 55.4% enriched uranium and finally enrich the 55.4% enriched uranium to 86.3% enriched uranium. I have increased the amount of HEU required from 20 kilograms to 21 kilograms to keep the quantity of U-235 in the product about the same.

The results for the first step can be found using separative work calculations but for the other two steps a SWU calculation would not produce accurate results. Since the plant at Natanz is designed to produce 3.5% product from natural uranium, its cascade is more tapered than is optimal for the upper stages of an enrichment plant designed to produce highly enriched uranium. As a result, some of the SWU output of the plant cannot be utilized during the latter cycles of the batch production process. The plant is restricted by the flow at the product end of the cascade. Therefore the time required per cycle is then determined by the amount of product required and the amount of product the plant can produce per day and not by a SWU calculation.

The results (Table 3) show that this method of batch recycling would take about 3 and one half months in contrast to the roughly one month required in Table 2. In addition Iran would need to start with 3,820 kilograms of 3.5% enriched uranium, much more than the 1,060 kilograms required by the calculations in Table 2 and significantly more than the 3,300 kilograms that Iran currently possesses. At current production rates it would take about three months before Iran will possess enough 3.5% enriched uranium to start the batch recycling process.

Table 3

Time, Product and Feed Requirements for the Production of HEU by Batch Recycling at the FEP (6,900 SWU per year total)
(Does Not Rely on Glaser's Analysis)

Cycle	Product Enrichment and Quantity	Feed Enrichment and Quantity	Time for Cycle (Days)
First	19.7% 324 kg	3.5% 3,820 kg	83
Second	55.4% 68.4 kg	19.7% 390 kg*	13
Third	86.3% 21 kg	55.4% 66.4	4
Total			106**

* Includes 68 kilograms of 19.7% enriched uranium that Iran has already stockpiled.
**Includes six days to account for equilibrium and cascade fill time.

Iran, however, has additional options for producing the HEU required for a nuclear weapon. As was stated above, in addition to the FEP, Iran is producing 19.7% enriched uranium at the PFEP, is producing 19.7% enriched uranium using two sets of two interconnected cascades at the FFEP and could quickly start a third set of interconnected cascades at the FFEP. Iran can use its 19.7% production capacity to carry out the final step of the three step batch recycling process. The results are shown in Table 4.

As in the previous case, the times for the second and third steps are determined by the cascade product production rate and not by SWU calculations. The total time required is little more than three months, which is about a week shorter than the prior case where all three batch recycling steps were carried out at the FEP. In addition, this method has the advantage of reducing the required amount of 3.5% enriched uranium feed from 3,820 kilograms to 1,650 kilograms, which is smaller than Iran's current 3,300 kilograms stockpile and therefore could be carried out today if Iran so desired.

Table 4

Time, Product and Feed Requirements for the Production of HEU by Batch Recycling at the FEP (6,900 SWU per year total)
Final Step at PFEP and FFEP
(Does Not Rely on Glaser's Analysis)

Cycle and Enrichment Plant	Product Enrichment and Quantity	Feed Enrichment and Quantity	Time for Cycle (Days)
First FEP	19.7% 140 kg	3.5% 1,650 kg	36
Second FEP	55.4% 39.4 kg	19.7% 225 kg*	8
Third PFEP & FFEP**	89.4% 20 kg	55.4% 39.0 kg	48
Total			98**

* Includes 68 kilograms of 19.7% enriched uranium that Iran has already stockpiled and 19 kilograms of 19.7% enriched uranium from the tails of the PFEP and FFEP.
** Plant inventory is 0.4 kilogram.
***Includes six days to account for equilibrium and cascade fill time.

If Glaser's calculations are incorrect, the only way that Iran could currently produce the HEU for a nuclear weapon in just two months would be to use batch recycling at the FEP combined with a clandestine "topping" enrichment plant. Since Iran continues to refuse to implement the Additional Protocol to its safeguards agreement, the IAEA would find it very difficult to locate a clandestine enrichment plant—a fact that the IAEA has continued to confirm.[25] While this has

[25] "While the Agency continues to verify the non-diversion of declared nuclear material at the nuclear facilities and LOFs declared by Iran under its Safeguards Agreement, as Iran is not providing the necessary cooperation, including

been a theoretical possibility since 2007, its salience increased with the discovery in September 2009 that Iran was actually building such a clandestine enrichment plant (the FFEP near Qom).

In this case, the clandestine enrichment plant could be designed as an ideal cascade to enrich 19.7% enriched uranium to the 90% enriched uranium needed for a nuclear weapon. By starting from 19.7% enriched uranium this clandestine enrichment plant need only contain about 1,400 IR-1 type centrifuges to be able to produce the 20 kilograms of HEU required for a nuclear weapon in just two months. Furthermore since Iran already has a stockpile of 19.7% enriched uranium, the production of the 19.7% enriched uranium at the FEP and the 90% enriched uranium at the clandestine enrichment plant could be carried out *simultaneously*.

The results of this process are shown in Table 5. As can be seen, the production of the 19.7% enriched uranium needed (including 0.5 kilograms for the plant inventory at the clandestine plant) to produce 20 kilograms of HEU at the clandestine enrichment plant now requires only 313 kilograms of 3.5% enriched feed. Since the cycle time at the FEP is shorter than that at the clandestine enrichment plant and the cycles are carried out simultaneously, the time required at the FEP has no impact on the overall time required to produce the HEU.

Table 5

Time, Product and Feed Requirements for the Production of HEU by Batch Recycling at the FEP (6,900 SWU per year total)
Final Step at 1,400 Centrifuge Clandestine Plant (0.9 SWU per centrifuge-year)
Cycles Carried out Simultaneously
(Does Not Rely on Glaser's Analysis)

Cycle and Enrichment Plant	Product Enrichment and Quantity	Feed Enrichment and Quantity	Time for Cycle (Days)
First FEP	19.7% 26.5 kg	3.5% 313 kg	9**
Second Clandestine	90.0% 20 kg	19.7% 106.8 kg*	63**
Total			63***

* Includes 68 kilograms of 19.7% enriched uranium that Iran has already stockpiled. Processing the tails of the clandestine plant at the PFEP and FFEP produces and additional 12.8 kilograms of 19.7% enriched uranium.
** Includes two days to account for equilibrium and cascade fill time.
*** Cycle times *not* additive since cycles are simultaneous.

by not implementing its Additional Protocol, the Agency is unable to provide credible assurance about the absence of undeclared nuclear material and activities in Iran, and therefore to conclude that all nuclear material in Iran is in peaceful activities." *Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions in the Islamic Republic of Iran*, GOV/2012/23, May 25, 2012, p.11.

Further, since Iran would have a substantial quantity of 3.5% enriched uranium left over (about 3,000 kilograms), Iran could continue the process and produce additional HEU. An additional 20 kilograms of HEU would require 1,109 kilograms of 3.5% enriched uranium feed, so with its current stockpile Iran could produce a total of about 74 kilograms of HEU, which is nearly enough for about four nuclear weapons. Since the clandestine enrichment plant has been sized to produce about 10 kilograms of HEU per month, Iran could produce enough HEU for a nuclear weapon at successive two month intervals.

Nor is batch recycling of enriched uranium the only pathway for Iran to produce the fissile material required for nuclear weapons, though it is the process that allows Iran to produce HEU most quickly. Iran could produce HEU at a clandestine enrichment plant designed to produce 90% enriched uranium from natural uranium feed.

A clandestine enrichment plant containing 3,800 centrifuges (0.9 SWU per centrifuge-year) could produce around 20 kilograms of HEU (the amount required for one nuclear weapon) each year using natural uranium as feed. Since this option does not require any overt breakout from safeguards, the relatively slow rate of HEU production would not necessarily be of any concern to Iran. Such production could be going on right now and the West might well not know. A clandestine enrichment plant would need a source of uranium but Iran is producing uranium at a mine near Bandar Abbas.[26] Since Iran has refused to implement the Additional Protocol to its IAEA safeguards, this uranium mining is unsafeguarded and the whereabouts of the uranium that Iran has produced there is unknown. A significant drawback to this stand-alone clandestine enrichment plant is that it requires many more centrifuges than would the 1,400 centrifuge clandestine plant discussed above. It is not clear whether Iran could provide this number of centrifuges to a clandestine plant and the larger any clandestine enrichment plant is, the more likely it is that it will be discovered.

Iran then, has a number of methods whereby it could produce the HEU required for a nuclear weapon. If Glaser's previously published calculations are correct, then batch recycling at the FEP alone could produce enough HEU for a weapon in just one month. If Glaser's calculations are incorrect, then the most threatening cases are those involving clandestine enrichment plants. If Iran were to produce 19.7% enriched uranium at the FEP and simultaneously enrich 19.7% enriched uranium to HEU at a clandestine enrichment plant, then it could produce a weapon's worth of HEU in two months and enough HEU for three weapons in six months. Alternatively, Iran might build a stand-alone clandestine plant to enrich natural uranium to HEU. Such a plant would only produce enough HEU for one weapon a year but since the plant could go undetected for many years, Iran could produce a sizable stockpile before detection.

If Glaser's calculations are incorrect, and one does not want to posit the existence of a clandestine enrichment plant, then the fastest way Iran could produce HEU would be to carry out batch recycling at the FEP and the final enrichment step at the PFEP and FFEP. In this fashion, Iran could produce sufficient HEU for a weapon in little more than three months which is longer than the one month that would be required if Glaser's calculations are correct. Clearly, it would be helpful to resolve the uncertainties regarding Glaser's calculations. However, even if these

[26] *Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions in the Islamic Republic of Iran*, GOV/2011/7, February 25, 2011, p.9.

uncertainties are not resolved, it is obvious that Iranian enrichment facilities pose a serious threat.

Appendix 2

Limiting Iran to Producing and Stockpiling Less Than 5% Enriched Uranium Does Not Prevent Easy Access to HEU

As was discussed in the text, many who propose a diplomatic solution with Iran have suggested that Iran should be allowed to continue to enrich uranium as long as this activity is subject to proper controls. In particular, they propose that Iran should not enrich uranium to more than 5% and that Iran's current stockpile of near 20% enriched uranium should be removed from Iran. Further, they propose that the size of Iran's enrichment effort be determined by the needs of Iran's peaceful nuclear program.

But Iran's current enrichment effort is quite small compared to those needed for most peaceful nuclear activities such as providing fuel for a single nuclear power reactor. A diplomatic solution could provide Iran with the justification for greatly expanding its current enrichment facilities as well as removing sanctions. Under these circumstances, Iran might receive assistance to expand its enrichment facilities (from say China or Pakistan) as part of normal nuclear commerce. These greatly expanded facilities would provide Iran easy access to the HEU needed for nuclear weapons.

For example, even if Iran produced only 4.1% enriched uranium[27] and expanded its enrichment capacity by about a factor of 12 (100,000 SWU/yr), it would only produce about 15 metric tons of enriched uranium per year. This amount would still be less than that needed to fuel a single large power reactor yet, using batch recycling, these enrichment facilities could produce enough HEU for a nuclear weapon in just two weeks. This process is shown in Table 6.

Table 6

Time, Product and Feed Requirements for the Production of 20 kg of HEU by Batch Recycling at a Centrifuge Enrichment Plant Designed to Produce 4.1% Enriched Uranium (100,000 SWU per year total) (Does Not Rely on Glaser's Analysis)

Cycle	Product Enrichment and Quantity	Feed Enrichment and Quantity	Time for Cycle (Days)
First	20.2% 304 kg	4.1% 1,990 kg	7.5
Second	60.2% 69.5 kg	20.2% 274 kg	1.7
Third	90.0% 20 kg	60.2% 39.5	0.5
Total			16*

*Includes six days to account for equilibrium and cascade fill time.

[27] With tails of 0.2%.

In the first step, 4.1% enriched uranium is processed into 20.2% enriched uranium. In the second step, this uranium is processed into 60.2% enriched uranium and the third step completes the process by producing the 20 kilograms of 90% enriched uranium needed for a nuclear weapon. Each step produces not only the material needed to be processed in the next step but the material needed for the plant inventory which in this case is 30 kilograms per step.

Instead of just producing enough HEU for one nuclear weapon, Iran could produce enough HEU for five nuclear weapons (100 kilograms) in a single batch recycling campaign. This process would take about five weeks and is shown in Table 7. This process would require starting with 6,090 kilograms of 4.1% enriched uranium but since the plant will be producing about 15,000 kilograms per year, it would not be hard for Iran to stockpile this quantity of enriched uranium.

Table 7

Time, Product and Feed Requirements for the Production of 100 kg of HEU by Batch Recycling at a Centrifuge Enrichment Plant Designed to Produce 4.1% Enriched Uranium (100,000 SWU per year total)
(Does Not Rely on Glaser's Analysis)

Cycle	Product Enrichment and Quantity	Feed Enrichment and Quantity	Time for Cycle (Days)
First	20.2% 929 kg	4.1% 6,090 kg	23
Second	60.2% 228 kg	20.2% 899 kg	5.6
Third	90.0% 100 kg	60.2% 198	2.5
Total			37*

*Includes six days to account for equilibrium and cascade fill time.

Iran's rapid expansion of its centrifuge enrichment capacity is already moving Iran towards such a capability. Restricting itself to just 3.5% enriched uranium Iran could even now produce enough HEU for a nuclear weapon in less than four months as is shown in Table 8. Since Iran already has a stockpile of 3,300 kilograms of 3.5% enriched uranium, Iran would have no trouble providing the 2,450 kilograms required.

Table 8

Time, Product and Feed Requirements for the Production of HEU by Batch Recycling at the FEP (6,900 SWU per year total)
Using 3.5% Enriched Uranium as the Starting Material
Final Step at PFEP and FFEP
(Does Not Rely on Glaser's Analysis)

Cycle and Enrichment Plant	Product Enrichment and Quantity	Feed Enrichment and Quantity	Time for Cycle (Days)
First FEP	19.7% 208 kg	3.5% 2,450 kg	53
Second FEP	55.4% 39.4 kg	19.7% 225 kg*	8
Third PFEP & FFEP**	89.4% 20 kg	55.4% 39.0 kg	48
Total			115**

* Includes 19 kilograms of 19.7% enriched uranium from the tails of the PFEP and FFEP.
** Plant inventory is 0.4 kilogram.
***Includes six days to account for equilibrium and cascade fill time