The potential value of stricter limits on Iran's stockpile of low-enriched UF_6

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(25 Sept. 2014)

Executive Summary

In the negotiation over Iran's nuclear program there currently appears to be an unbridgeable gap between Iran's minimum requirement for enrichment capacity, the equivalent of the approximately 10,000 IR-1 centrifuges currently operating at Natanz, and the U.S. upper limit, which appears to be considerably lower.

But there is another variable which also determines how quickly Iran could produce enough 90% enriched uranium for a nuclear explosive if it broke its commitment to stay below 5% enrichment. This variable is the size of Iran's stockpile of up-to-5%-enriched uranium. Having a large stockpile of low-enriched uranium to feed into its centrifuge cascades shortens by a factor of three, e.g. from six to two months, the time that it would take to produce enough 90% enriched uranium for a bomb. We show that it would possible to reduce Iran's current stockpile of 5,000 kg of low-enriched UF_6 to about 200 kg. This would make it possible to recover the factor of three in breakout time and might make it possible for the P5+1 to raise their upper limit on Iran's centrifuge capacity.

The impasse over Iran's enrichment capacity

Currently, Iran has a total of 9,484 IR-1 centrifuges operating at Natanz.[1] Each IR-1 has a uranium enrichment capacity of between 0.7 and 1.0 Separative Work Units (SWUs) per year.[2] Iran's total operating enrichment capacity at Natanz therefore is between 6,600 and 9,500 SWUs per year.

Iran does not want to decrease this capacity. Some of the P5+1 countries negotiating with Iran are concerned, however, that with this enrichment capacity, Iran could quickly break out of the Non-Proliferation Treaty and produce a weapon-quantity of highly enriched uranium from its stockpile of low-enriched UF_6.

The concern about "breakout"

The IAEA assumes that a "significant quantity" of HEU, i.e. a quantity sufficient to make a first-generation implosion nuclear weapon plus the material that would be lost to production scrap, would contain 25 kg of U-235. A significant quantity of weapon-grade (90% enriched) uranium therefore would be 27.8 kg. Currently, Iran has stockpiled 5,250 kg of uranium in UF_6 enriched to an average level of about 3.4%.[3] It would require 925 kg of this stockpile and 1,520 SWU of enrichment to produce a significant quantity of weapon-grade uranium.[4] Therefore, if Iran

[1] 9,156 in Hall A + 328 in the Pilot Plant, "Implementation of the NPT Safeguards Agreement and relevant
[2] David Albright, et al, "ISIS Analysis of IAEA Iran Safeguards Report," 5 September 2014, Table 1 and Figure 11.
[3] 7765 kg of UF_6, IAEA, GOV/2014/43, 5 September 2014, para. 21. To obtain the uranium content of UF_6, multiply the weight by 0.676. IAEA reports characterize this material as enriched to "up to 5%" but, when discussing its use, report its average enrichment as 3.4%
[4] Assuming that the depleted uranium contains 0.72% U-235, i.e. the same as natural uranium. It should be emphasized that the quantities of uranium discussed here are uranium in UF_6 or UO_2. Some calculations, e.g. at

reconfigured its cascades to produce weapon-grade uranium, the time required for it to produce a significant quantity of weapon-grade UF_6 with the IR-1 centrifuges currently operating at Natanz would be two to three months. To this should be added the time required to reconfigure the cascades – estimated by some independent breakout analysts as about two weeks.[5]

Focus on UF_6 stockpile as well as centrifuge capacity

Although the focus in the negotiations apparently has been on limiting centrifuge numbers, the stored enrichment work in the available low-enriched uranium is another important variable contributing to the short breakout time calculated above.

To illustrate the importance of the stored enrichment work, consider the situation if Iran had no stockpile of low-enriched uranium in country. It then would have to resort to enriching natural uranium. This would require about three times as much enrichment work (4700 SWU) to produce a significant quantity of weapon-grade uranium[6] and would take proportionately longer, 6 to 8.5 months. This length of time might be seen as less problematic by the P5+1.

Making Iran's stockpile of 3.4% enriched uranium unavailable for further enrichment

Iran plans to use its 3.4% enriched uranium to produce fuel for the Bushehr reactor. This fuel is made up of cylindrical pellets of UO_2 stacked inside long zirconium-alloy tubes. In the Joint Plan of Action, Iran committed to cap its stockpile of UF_6 enriched up to 5% (assumed here to average 3.4%) by converting newly enriched UF_6 to UO_2. Iran began conversion in July 2014 and, within about a month, had fed 1505 kg of UF_6 into the conversion process.[7] At this rate, Iran could convert its entire 7765 kg stockpile of 3.4% enriched UF_6 into UO_2 within about half a year.

Currently, Iran is producing per month about 216 kg of UF_6 containing 146 kg of uranium enriched to 3.4%.[8] About 925 kg of 3.4% enriched uranium feed would be required to produce one significant quantity of 90% enriched uranium if there were no process losses.

A strategy for maximizing the breakout time for a given enrichment capacity therefore would be to minimize the amount of 3.4% UF_6 available to be enriched. If only 200 kg of 3.4% enriched UF_6 were available, then the breakout time, not including cascade reconnect time, would be between 5.1 and 7.3 months.[9]

Of course, it would be possible for Iran to convert the low-enriched UO_2 back into UF_6. How long this would take would have to be estimated but additional steps could be taken beyond

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http://nuclearenergy.ir/irans-practical-needs-iran-want-fuel-reactors, apply the formula for enrichment work incorrectly to the total mass of UF_6 and obtain requirements 1.5 times higher as a result.

[5] Patrick Migliorini, David Albright, Houston Wood, and Christina Walrond, "Iranian Breakout Estimates, Updated September 2013" (Institute for Science and International Security, 2013).

[6] With a depleted uranium assay of 0.4%.

[7] IAEA, GOV/2014/43, 5 September 2014, para. 55.

[8] Based on the fact that Iran had produced cumulatively 12,464 kg of low-enriched UF_6 at the Natanz Fuel Enrichment Plant as of 12 August 2014 (IAEA, GOV/2014/43, 5 September 2014), para. 25 and 11,767 kg as of 13 May 2014 (IAEA, "Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions in the Islamic Republic of Iran," GOV/2014/28, 23 May 2014, para. 17) for a difference of 697 kg over 14 weeks. A small amount of additional low-enriched UF_6 was produced by the 328 centrifuges in the Natanz Pilot Plant.

[9] The quantity of SWUs required to produce a significant quantity of 90% enriched uranium from a mass of 3.4% enriched uranium feed $M_{3.4}$ that is less than 925 kg, supplemented with natural uranium is 4700 -3180($M_{3.4}$/925) SWU. When $M_{3.4}$ = 925 kg, this formula gives 1520 SWU. When $M_{3.4}$ = 200 kg, it gives 4012 SWU.

conversion to oxide to make it more difficult or impossible to convert the low-enriched uranium back into UF_6 for further enrichment. These steps include fabrication into fuel in Iran or shipment out of country for fabrication into fuel.

Remove from Natanz. To start with, Iran's stockpile of 3.4% enriched uranium in the form of UF_6 at Natanz could be limited to less than 200 kg if Iran collected the 3.4% enriched UF_6 it is producing in 12A or 12B containers and shipped each one off-site as soon as it was full.[10] These containers, which are designed to hold up to 209 kg of UF_6 (141 kg uranium) enriched up to 5 percent, have about one tenth of the capacity of the 30B containers typically used to transport low-enriched UF_6 to conversion facilities.

Convert into UO_2 and fabricate into fuel. If the 3.4% enriched UF_6 were shipped to the Esfahan fuel fabrication facility and converted into UO_2 pellets and then fuel assemblies for the Bushehr reactor on a just-in-time basis, then it would be necessary to chemically process the fuel to recover the oxide before it could be converted hack into UF_6.

According to Iranian officials, RosAtom has agreed that Iran can supply four fuel assemblies a year for the Bushehr reactor. Assuming that the four fuel assemblies contain about 1.7 tons of 3.4 to 4.3% enriched uranium[11] and that the depleted uranium assay is 0.3–0.4%, producing the low-enriched uranium would require 6,000 to 10,000 SWU per year – in the same range as the currently operating enrichment capacity at Natanz.

Ship out of Iran. Iran has not yet demonstrated the capacity to produce fuel assemblies for the Bushehr VVER-1000 reactor. Each VVER-1000 fuel assembly contains 182 fuel rods[12] and about 425 kg of low-enriched uranium. In 2011, Iran fabricated two assemblies, of test fuel rods, each containing 6 kg in 12 rods of 3.4% enriched UO_2 for irradiation testing in the Tehran Research Reactor.[13] No Bushehr-type fuel rods have been produced since.

Until Iran is able to produce fuel assemblies for Bushehr at a rate that can keep up with its production of low-enriched UF_6, it could send its 3.4% enriched UF_6 or UO_2 to Russia or another country[14] for fabrication into VVER-1000 fuel assemblies. To minimize the inventory of 3.4% enriched uranium in country and thereby maximize warning time of a breakout, 12A or 12B canisters of newly produced UF_6 could be shipped to the fuel fabricator as soon as they were full.

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[10] The 12 stands for the canister outside diameter in inches. A is made of nickel and B of nickel-copper alloy, B. M. Biwer, F. A. Monette, L. A. Nieves, and N. L. Ranek, *Transportation Impact Assessment for Shipment of Uranium Hexafluoride (UF_6) Cylinders from the East Tennessee Technology Park to the Portsmouth and Paducah Gaseous Diffusion Plants,* (Argonne National Laboratory, ANL/EAD/TM-112, 2001) Table B.2.

[11] Y. M. Semchenkov, et al., (Kurchatov Institute) "Advanced Fuel Cycles For VVER-1000 Reactors.

[12] *A VVER-1000 LEU and MOX Assembly Computational Benchmark*, www.oecd-nea.org/science/docs/2002/nsc-doc2002-10.pdf.

[13] "Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions in the Islamic Republic of Iran, GOV/2012/9, 24 February 2012, para. 37 and IAEA, GOV/2014/43, 5 September 2014, Table 5.

[14] Russia is not the only country that can produce fuel for Russian designed reactors. In 2008, Westinghouse, now owned by Toshiba, contracted to supply fuel for some of Ukraine's VVER-1000s, "Weekly roundup," *Nuclear Intelligence Weekly,* 22 August 2014, p. 1. ENUSA of Spain makes fuel for Finland's, VVER-440s, www.enusa.es/eng/actividad/fabricacion.html.

The precedent of Iran's stockpile of 19% enriched uranium

An even more acute case of stored enrichment work has already been confronted with a stockpile of 303 kg of uranium that Iran enriched up to about 19% U-235. If this uranium were enriched further to weapon-grade, a significant quantity of weapon-grade uranium could be produced from it with an expenditure of only 300 SWUs.[15] In response to P5+1 concern about this material, Iran committed in the 24 November 2013 "Joint Plan of Action" to turn it into U_3O_8 and then fuel for the Tehran Research Reactor (TRR) or blend it down to no more than 5% enrichment. [16] As of the IAEA's September 2014 report, Iran had blended down 74.4 kg of the 19% enriched uranium, used 34 kg to fabricate fuel for the TRR, had 96.8 kg unused in the form of UO_2 with the remaining 97 kg in conversion and fuel production waste.[17]

The 19% enriched U_3O_8 would have to be converted back into UF_6 before it could be further enriched to weapons-grade. Iran committed in the Joint Plan of Action not to maintain a line that could convert 19% enriched UO_2 back into UF_6,[18] and the IAEA has confirmed that there is no such line at the Esfahan Uranium Conversion Facility.[19] It could take years to convert the remaining 19% enriched UO_2 in storage and waste into TRR fuel, however.[20]. One way in which Iran could reduce concern about this material would be to dilute the 19% uranium in the waste down to an enrichment of a few percent.

Are we worrying too much about breakout?

Designing an agreement to forestall a potential breakout by Iran using IAEA-safeguarded facilities has become a major focus of the negotiations. Many consider such a breakout implausible, however, because Iran could not be certain that there would not be quick military action as soon as the IAEA reported the breakout. Also, if Iran did decide it needed nuclear weapons, it would surely want more than one.

Such considerations may have been behind the conclusion in the U.S. 2007 National Intelligence Estimate, *Iran: Nuclear Intentions and Capabilities* that

> "We assess with moderate confidence that Iran probably would use covert facilities – rather than its declared nuclear sites – for the production of highly enriched uranium for a weapon."[21]

If this is the case, having a good system for verifying Iran's centrifuge production and distribution may be more important than guaranteeing that it would take at least a year to execute a breakout in which Iran would openly launch a vulnerable program to acquire a single nuclear explosive.

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[15] Total quantity of 19% uranium produced by Iran from IAEA, GOV/2014/43, 5 September 2014, Table 1. SWUs required to produce weapon-grade uranium calculated assuming a depleted uranium assay of 3.5%.

[16] IAEA, "Communication dated 27 November 2013 received from the EU High Representative concerning the text of the Joint Plan of Action," INFCIRC/855, 27 November 2013.

[17] IAEA, GOV/2014/43, 5 September 2014, paras. 60, 71, footnote 54, and Tables 2, 4 and 7.

[18] *Ibid.*

[19] IAEA, GOV/2014/43, 5 September 2014, para. 59.

[20] The TRR has two types of fuel assemblies: a standard assembly contains 1.4 kg of 19% enriched uranium and a control rod assembly contains 1.0 kg, IAEA, GOV/2014/43, 5 September 2014, Table 7. As of September 2014, 26 assemblies had been produced. Based on previous IAEA reports, none had been produced since May 2014, 10 between May 2013 and May 2014, and the remaining 16 before that, starting in early 2012.

[21] *Iran: Nuclear Intentions and Capabilities* (US National Intelligence Council, 2007).