Iran's Centrifuge Research and Development Program

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The interim steps under the Joint Plan of Action are not expected to seriously affect Iran's centrifuge research and development program. These steps may delay the final development of new centrifuges that have not yet used uranium hexafluoride at the Natanz Pilot Fuel Enrichment Plant. However, Iran can continue development of several existing types of advanced centrifuges there. More significant limitations on Iran's centrifuge R&D combined with greater transparency of this program should be included in the final step of a comprehensive solution, given that Iran's development of more advanced centrifuges would greatly ease its ability to conduct a secret breakout to nuclear weapons.

Concerns have arisen about Iran's centrifuge research and development (R&D) activities that are allowed under the interim steps outlined in the Joint Plan of Action (JPA) signed in Geneva on November 24, 2013. This document specifies that "Iran will continue its safeguarded R&D practices, including its current enrichment R&D practices, which are not designed for accumulation of the enriched uranium."[1] A key part of Iran's centrifuge R&D activities occurs at the Natanz Pilot Fuel Enrichment Plant (PFEP) where Iran tests several advanced centrifuges with uranium hexafluoride, a material which requires International Atomic Energy Agency (IAEA) safeguards. An interpretation of this statement in the JPA is that these safeguarded centrifuge R&D activities would be limited or frozen.

The extent of R&D activities at the pilot plant became an issue in December 2013 during negotiations on the implementation of the interim steps when Iran reportedly sought to feed uranium hexafluoride into an advanced centrifuge type at the Natanz pilot plant that either had not been previously installed or that had been installed but had not used uranium hexafluoride. This action appears to have been prevented during the negotiations, helping solidify the interpretation that centrifuge R&D activities should be limited during the interim period.

The technical understandings related to the implementation of the interim steps announced on January 11, 2014 clarified that Iran can continue safeguarded centrifuge R&D practices at the level described in the November 2013 IAEA safeguards report on Iran, according to a State Department briefing on January 13, 2014[2] and interviews with those who have read the technical understandings document.

[1] Joint Plan of Action, November 24, 2013, p. 2, http://eeas.europa.eu/statements/docs/2013/131124_03_en.pdf.
[2] Transcript available at: http://www.state.gov/r/pa/prs/ps/2014/01/219571.htm.

What this condition means in practice is that the centrifuges which were being fed uranium hexafluoride at the Natanz Pilot Fuel Enrichment Plant in November 2013 can continue to be fed uranium hexafluoride.

The technical understandings document is reportedly less clear about centrifuge R&D activities that involve centrifuges not being fed with uranium hexafluoride at Natanz or elsewhere. One interpretation is that they should also be limited to the levels existing in November 2013. R&D activities are believed to be taking place at other sites that are not subject to regular inspections under Iran's comprehensive safeguards agreement. At least one of these sites is known, namely the Kalaye Electric site, but others are unknown. These activities will remain unmonitored by the IAEA during the period of the interim steps, so it is unclear what level of centrifuge R&D Iran will carry out outside of the Natanz pilot plant. In practice, Iran is free to carry out work on new centrifuges at these sites with little fear of being detected.

In sum, Iran can continue centrifuge enrichment R&D in several advanced centrifuges at the Natanz pilot plant and carry out centrifuge R&D not involving uranium hexafluoride. As a result, the interim steps are not expected to seriously affect Iran's centrifuge R&D activities. They may delay the development of new centrifuges that have not yet used uranium hexafluoride. However, Iran can continue the development of several advanced centrifuges with enrichment capabilities that far exceed the IR-1 centrifuge, which is the main centrifuge Iran has deployed to date.

More significant limitations on Iran's centrifuge R&D should be included in the comprehensive solution, given that Iran's development of more advanced centrifuges would greatly ease the potential breakout to nuclear weapons in secret. A centrifuge ten times more capable than the IR-1 centrifuge would require ten times fewer centrifuges to make the same amount of weapon-grade uranium for nuclear weapons, allowing for much smaller facilities, fewer personnel, and procurement of less material. Centrifuge R&D could also lead to breakthroughs in materials or methods that would further strengthen a secret breakout effort and make both the implementation and verification of a comprehensive solution extremely difficult.

R&D at Natanz Pilot Fuel Enrichment Plant

Iran's safeguarded R&D activities involve the feeding of uranium hexafluoride into a range of advanced centrifuges at the Pilot Fuel Enrichment Plant at Natanz, about 25 miles southeast of the city of Kashan. The Natanz pilot plant replaced the Kalaye Electric site which was the primary centrifuge research and development site in the late 1990s and early 2000s. The significance of Kalaye Electric to Iran's nuclear program is discussed in more detail below.

The PFEP's original purpose was to test the performance of centrifuges with uranium hexafluoride prior to installation of production-scale cascades at the Fuel Enrichment Plant (FEP) at Natanz, the Fordow facility, or possibly other enrichment facilities. It can hold six 164-centrifuge cascades. In February 2010, Iran started producing near 20 percent low enriched uranium (LEU) hexafluoride ($LEUF_6$) in two cascades of IR-1 centrifuges joined together by piping into a tandem cascade.[3]

The PFEP was divided into two areas: cascades 1 and 6 were designated for IR-1 centrifuges to produce near 20 percent LEU hexafluoride, and Cascades 2, 3, 4 and 5 were declared for research and development of centrifuges, mainly advanced ones. In these R&D cascades, natural uranium hexafluoride is enriched up to five percent; then the enrichment level is measured with a mass spectrometer. Subsequently, the enriched uranium is remixed with the waste or tails, creating natural uranium again. Thus, no enriched uranium enters the product tanks from these cascades, or - in the terms of the Joint Plan of Action - enriched uranium is not accumulated.

On January 20, 2014, under the Joint Plan of Action, Iran stopped the production of near 20 percent LEU in two cascades in the PFEP and four cascades at the Fordow enrichment site. Enrichment in these cascades is not banned, and Iran may produce LEU (<5 percent) there.

Permitted R&D at the PFEP under Interim Steps

Iran's centrifuge R&D activities at the PFEP are limited by the status of these activities as reported in the November 14, 2013 IAEA safeguards report. As of November 3, 2013, according to this report, the PFEP's R&D area housed 371 centrifuges, 357 of which were advanced centrifuges; the rest were IR-1 centrifuges. Iran was intermittently feeding natural hexafluoride into the IR-1, IR-2m, IR-4, IR-6 and IR-6s centrifuges, both into single machines and cascades of varying sizes. Natural uranium hexafluoride was yet to be introduced into the IR-5 centrifuge.[4]

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[3] For details see: William C. Witt, Patrick Migliorini, David Albright and Houston Wood, "Modeling Iran's Tandem Cascade Configuration for Uranium Enrichment by Gas Centrifuge," July 14-18, 2013 INMM conference paper, http://isis-online.org/uploads/isis-reports/documents/WCWitt__Modeling_Irans_Tandem_Cascade_Configuration_for_Uranium_Enrichment_by_Gas_Centrifuge.pdf.

[4] Director General IAEA, *Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions in the Islamic Republic of Iran*, GOV2013/56, November 14, 2013, p. 6.

Table 1 shows the type and number of advanced centrifuges in cascades 2 to 5 from 2011 through 2013.

Centrifuge Type	**2011**				**2012**				**2013**			
	Feb.	May	Sept.	Nov.	Feb.	May	Aug.	Nov.	Feb.	May	Aug.	Nov.
	Cascade 2											
IR-4	*	**	*	*	*	*	10	32	29	19	17	14
IR-5	0	0	0	0	0	0	0	0	0	1	1	1
IR-6	0	0	0	0	0	0	0	0	6	14	12	13
IR-6s	0	0	0	0	0	0	0	0	2	3	8	1
	Cascade 3											
IR-1	*	**	**	*	*	*	0	*	2	19	18*	14
IR-2m	*	**	**	*	*	*	0	14	9	3		2
	Cascade 4											
IR-4	0	0	27	66	58	129	123	144	164	164	164	164
	Cascade 5											
IR-2m	0	0	136	164	164	164	162	162	162	162	162	162

Table 1. Source: Implementation of the NPT Safeguards Agreement in Iran reports 2011-2013. Available at: http://isis-online.org/iaea-reports/category/iran/#2013.
* Centrifuges present but no breakdown by centrifuge type available in the reports.
** No mention of centrifuge type in the reports.

Most of the advanced centrifuges were in cascades 4 and 5, which had 164 IR-4 centrifuges and 162 IR-2m centrifuges, respectively. These production-scale cascades were involved in final testing before the deployment of these centrifuges. The IR-2m centrifuge appears to be favored based on the recent deployment of about 1,000 of them in the Natanz Fuel Enrichment Plant.

Based on the technical understandings document, it appears that Iran will be allowed to conduct R&D with uranium hexafluoride at the PFEP using five types of centrifuges: IR-1, IR-2m, IR-4, IR-6, and IR-6s. Since the IR-5 was not yet being fed with uranium hexafluoride on November 3, 2013, it could legitimately operate but not be fed with uranium hexafluoride during the period of the interim steps.

Very little information is available about the IR-5, IR-6, and IR-6s centrifuges. More is known about the IR-2m and IR-4 centrifuges but lacking is basic information about the enrichment capacity these machines have achieved in practice while operating in a production-scale cascade.

One disadvantage of Iran not producing enriched uranium is that it significantly complicates estimates of the enrichment capability of these centrifuges. Based on statements by Iranian officials, the IR-2m centrifuge is estimated to have an enrichment output of about 3-5 separative work units per year per centrifuge while operating in a production-scale cascade. This output is considerably better than the output of the IR-1 centrifuge.[5] However, reliable data which could confirm this output is lacking.

Other Sites Conducting Centrifuge R&D

Verified limitations imposed by the interim steps on Iranian centrifuge R&D seem to be restricted to the Pilot Fuel Enrichment Plant at Natanz where uranium hexafluoride has been introduced into the centrifuges, which necessarily entails IAEA safeguards. Other sites involved in centrifuge R&D are not safeguarded under Iran's comprehensive safeguards agreement and do not appear to be monitored in any way under the Joint Plan of Action. Activity at those facilities would likely not involve the secret use of uranium hexafluoride, since this act would be a violation of Iran's safeguards agreement with the IAEA. However, this conclusion has not been confirmed by the IAEA and requires verification. Furthermore, Iran could conduct fairly extensive testing without introducing uranium hexafluoride into an advanced centrifuge cascade but instead using inert gas.

The number of Iranian facilities engaged in centrifuge R&D is not known. Moreover, the nature of the activities carried out at these sites is unclear. Nonetheless, these sites are likely conducting valuable R&D without the use of uranium hexafluoride, including design work, limited centrifuge manufacturing and assembly, and tests involving the spinning of rotors in air or under vacuum, often called mechanical testing. Mechanical testing is vital, and extensive mechanical testing would usually occur before a centrifuge would be brought to Natanz and tested with uranium hexafluoride. Afterwards, more mechanical testing of that centrifuge could also occur outside of Natanz.

One of such unsafeguarded sites is Kalaye Electric, until 2003 Iran's primary centrifuge R&D site and still an important part of its centrifuge research and development activities. Figure 1 shows commercial satellite imagery of the site in north Tehran.

[5] Each quarter, the IAEA publishes the amount of natural uranium feed fed into all the centrifuges in the R&D section of the PFEP. With many assumptions, a crude estimate of the average enrichment output of a centrifuge in the R&D section can be made. However, Iran enriches in these centrifuges intermittently, so the duration of the actual enrichment of the centrifuges in the cascades is not known, furthering uncertainties about any such estimate. Nonetheless, the crude calculation shows that the average enrichment output of the advanced centrifuges at the PFEP could be exceeding 2 swu/yr/centrifuge and possibly reaching about 3 swu/yr/centrifuge, assuming the cascades are enriching half the time. The IR-2m and IR-4 centrifuges dominate these estimates, suggesting that they have significantly greater enrichment outputs than the IR-1 centrifuge.

Figure 1. Digital Globe/Google Earth imagery showing the centrifuge R&D facility Kalaye Electric in January 2004 (top) and July 2013 (bottom). The facility is located in several buildings within the yellow boundary. Prior to Iran moving out of Kalaye Electric in 2003, the centrifuge test cascade was in a building below the site entrance in the upper image and some single centrifuge tests were conducted in the workshop, which is the long building on the right side of the site in the images (gray-roofed building in the upper image and white-roofed in the lower image). The test bed was installed in an old garage at the site after 2006 (see lower image).

Until 2003, Kalaye Electric was a secret centrifuge site involved in enriching uranium in violation of Iran's safeguards agreement with the IAEA. In early 2003, the site was revealed publicly by the National Council for Resistance of Iran (NCRI) although Iran still did not admit the site's purpose, which led to a conflict with the IAEA. In the fall of 2003, Iran reversed itself and admitted that Kalaye Electric had indeed been its main centrifuge R&D site prior to moving key operations to Natanz and had engaged in activities violating Iran's non-proliferation commitments.

The importance of Kalaye Electric faded after 2003 during the period of the suspension of Iran's centrifuge program that was negotiated with the European Union. During the suspension, Iran could conduct only "theoretical" centrifuge R&D. The IAEA made a few complementary access visits to Kalaye Electric during this period, but the inspectors reported nothing of note. When the implementation of the Additional Protocol was discontinued in 2006, the IAEA's access to centrifuge R&D facilities faded. Afterwards, Iran increased its centrifuge R&D efforts at this site, although precisely when this happened is not clear.

In January 2008, the IAEA's Director General and Deputy Director General for Safeguards visited the centrifuge R&D laboratory at Kalaye Electric and learned of activities being carried out there. At the time, Iran was working on "four different centrifuge designs: two subcritical rotor designs, a rotor with bellows and a more advanced centrifuge."[6] One was the IR-2m, which has two carbon fiber rotor tubes connected by a maraging steel bellows. Iran expected the IR-2m centrifuge to have an enrichment output exceeding 6 separative work units (swu) per year per centrifuge and have a target enrichment output exceeding 10 swu/yr/centrifuge.[7] According to Iran, the site was also developing centrifuge components and centrifuge-related equipment. Each centrifuge design had its own design team, and the site had a "test bed" for mechanical testing of the designs (see figure 1). However, not all design teams worked at Kalaye Electric, implying that there was another centrifuge R&D site, at least in 2008 when the visit occurred.

It is thus not possible to rule out the existence of other centrifuge R&D sites. One site that deserves further scrutiny is Farayand Technique, which is located in an industrial park in a valley near Esfahan. According to former senior U.N officials close to the IAEA, inspectors who visited this site during the 2003-2006 suspension suspected that the site could have been originally intended as a back-up to the Kalaye Electric facility or perhaps even as the pilot centrifuge plant. At the time, the site had two centrifuge test stands and a test pit, which would have been capable of mechanically testing centrifuges. Next to this facility was a large building under construction, which may have been intended to be the pilot centrifuge plant before the decision

[6] IAEA Director General, *Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions 1737 (2006) and 1747 (2007) in the Islamic Republic of Iran*, GOV/2008/4, February 22, 2008.
[7] This two rotor tube supercritical centrifuge uses carbon fiber and the increase in output to over 10 swu/yr/centrifuge assumed that Iran could achieve very high rotational speeds. As noted earlier, the current enrichment output of the IR-2m centrifuge is estimated to be in the range of 3-5 swu/yr/centrifuge while in production-scale cascades, which would imply a reduced rotational speed or more frequent breakage in such a cascade.

was made to establish it at Natanz. The Farayand building was far bigger than the building housing the pilot centrifuge plant at Natanz. In this case, Farayand Technique would have also served as a centrifuge assembly plant. According to former senior United Nations officials close to the IAEA, there remain questions about the original intended role of the Farayand site and the fate and use of any equipment that was or remains there. One question is whether today this site plays any role in the production and testing of centrifuges, including advanced ones.

Another site deserving of scrutiny is Pars Trash, a subsidiary of Kalaye Electric located in Tehran that prior to 2004 was involved in centrifuge manufacturing and concealment activities aimed at defeating the IAEA's efforts to uncover Iran's centrifuge R&D program. This site received centrifuge manufacturing and development equipment from Kalaye Electric. It is located in Tehran among warehouses and light industrial buildings about a kilometer west of the Kalaye Electric facility. Prior to 2004, it manufactured centrifuge outer casings. Pars Trash was originally a small, private factory involved in making automobile parts. It went bankrupt and was bought by the Kalaye Electric Company, or its subsidiary, Farayand Technique. In February 2003, Pars Trash was involved in Iran's concealment efforts. The facility stored centrifuge equipment that had been hastily moved from Kalaye Electric in an attempt to prevent its discovery by IAEA inspectors who were seeking access to that site. As in the case of Farayand, it is unclear whether this or possibly other sites have a current role in the production and testing of centrifuges, including advanced ones.

The cases of the Kalaye Electric, Farayand Technique, and Pars Trash sites show that important centrifuge R&D activities have occurred outside of IAEA scrutiny and that Iran has a history of hiding important parts of its centrifuge R&D complex. This situation poses significant challenges for arriving at a long-term solution.

Comprehensive Solution under Joint Plan of Action

Iran's centrifuge R&D program poses several risks to the verifiability of a comprehensive solution under the Joint Plan of Action. Negotiations on a comprehensive solution should seek to place further limitations on this program and establish effective monitoring practices, as part of an agreement on a mutually defined enrichment program with mutually agreed parameters. Limiting Iran's centrifuge R&D program and improving the monitoring of any remaining activities is a priority.

To that end, under a comprehensive solution, all centrifuge R&D activities should be declared to the IAEA and conducted only at the Natanz enrichment site, which should be the only enrichment site that exists under a comprehensive solution. All centrifuge testing, with or without nuclear material, would occur at this site. In particular, this site would be the sole location to test rotor assemblies, whether tested in air, under vacuum, or with uranium hexafluoride.

It is equally important to limit the capability of Iran's centrifuges, so as to make breakout in secret significantly more difficult. Thus, centrifuge R&D should be limited to centrifuges that are roughly comparable to the current capability of the IR-2m centrifuge, which Iran has started deploying at the Natanz Fuel Enrichment Plant. This would be accomplished by capping the theoretical equivalent enrichment output of any centrifuge at no more than five swu in kilograms of uranium per year. Iran would stop all work on more capable advanced centrifuges.

These limitations and increased monitoring would be important in achieving a long-term comprehensive solution which would ensure that Iran's nuclear program is exclusively peaceful.