The Iranian Nuclear Programme

Practical Parameters for a Credible Long-Term Agreement

Olli Heinonen

CENTRE FOR THE NEW MIDDLE EAST
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Front Cover Image: Press conference after nuclear negotiations concluded at the United Nations Headquarters in Geneva, Switzerland © US Department of State

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The Imperatives of a Credible Nuclear Agreement With Iran

Iran and the P5+1 (China, France, Germany, Russia, the United Kingdom, and the United States) are continuing negotiations to achieve a comprehensive nuclear agreement. Whilst the wider political context to such an agreement is of importance, the key concern at this stage of the negotiations must revolve around ensuring that any agreement guarantees Iran is left without a pathway to making nuclear weapons. As such, what follows below is concerned narrowly with elucidating the detailed considerations P5+1 negotiators have to account for in setting the parameters for a nuclear agreement with Iran. It offers a realistic, independent assessment of Iran's pathway to the bomb and the necessary constraints that will make for an acceptable deal.

Since the negotiations are now at a juncture at which the ideal scenario of having no enrichment or heavy water research reactor programme in Iran after any deal is increasingly unlikely, it is imperative that any concession that Iran is to retain a limited well defined nuclear programme as part of an agreement must firmly rest on the following pillars:

- An effective verification regime
- Adequate irreversibility of constraints with early detection of violations
- Sufficient response time in case of violations
- Verifiable dismantlement of elements related to military dimension

Achieving these basic building blocks will necessitate a significant re-shaping and scale-back of the scope, content and parameters of Iranian activity, with many elements to consider:

No deal will be credible or durable if intensified, sustained verification is absent. The IAEA must be able to provide prompt warning of violations, determine the correctness and completeness of Iran's declarations, and establish the accurate scope of Iran's nuclear programme, including undeclared nuclear activities or facilities. It must be credibly able to provide assurances on the absence of nuclear weapons related activities in Iran. Iran must further verifiably stop its efforts to procure key proliferation-sensitive goods illegally, which will require a continuation of national and United Nation Security Council sanctions on proliferation sensitive goods for the long term.

Inspections alone are not enough however, any deal must hold Iran to a satisfactory level of irreversibility in the actions it takes to curtail its nuclear activities. Progress on the Arak nuclear reactor, for example, has proceeded apace and it is now deemed to be capable of producing sufficient weapons-grade plutonium for two nuclear weapons annually, if the reactor is completed. Iran's suggestions to address this so far have been based on easily reversible design changes. A proliferation proof approach would be to remove the currently installed core and replace it with a smaller one that would significantly reduce the potential to produce weapons-grade plutonium.

In constructing the parameters under which Iran retains a civilian nuclear programme, the basis to operate on must also be to recognise that we do not have a full picture of the programme. Among other problems, the number of centrifuges operating in Natanz and Fordow are well known, but the IAEA has not been able to establish a full inventory of all types of centrifuges manufactured in Iran, and their current location. Therefore, the technical parameters will have to be crafted to limit ambiguities to a minimum. For example, agreeing to a higher number of centrifuges in Natanz, and compensating the attendant shortened break-out time with a smaller declared enriched uranium inventory, is not a credible solution when the total amount of uranium in Iran remains unverified, and types and

inventories of centrifuges are not known.

Since centrifuges appear to have become the main unit of currency in the wider debate around the negotiations over Iran's nuclear programme, notwithstanding the many considerations that follow below, it should be stated categorically that limiting Iran's centrifuge programme to between 2,000 and 4,000 IR-1 centrifuges is consistent with Iran's actual needs for enriched uranium for many years. Even 2,000 IR-1 centrifuges would provide Iran with sufficient enriched uranium for its existing and foreseen research reactor needs.

Throughout the long history of discussions, Iran has often offered 'transparency' to build international confidence about the nature of its nuclear programme. Such transparency should be understood and implemented in a meaningful and systematic way. Even in the name of 'transparency,' where Iran decides to 'show' a place previously off limits (imposed by Iran), such inspection visits can have meaning only if substantially new information and discussions take place, and explanations are provided on the scope and content of the nuclear programme. Hence openness must be clearly defined and become a legally binding undertaking in an agreement rather than be treated as goodwill visits to be granted when problems arise. Given the long lead times inherent to inspections and other actions related to verification and implementation through international fora, an agreement must also provide sufficient time to mount an effective response to major violations by Iran.

Finally, Iran's most serious verification shortcoming remains its unwillingness to address the IAEA's concerns about the past and possibly on-going military dimensions of its nuclear programme. Unless Iran satisfies the IAEA in this key area it is impossible for Western negotiators to conclude that all of Iran's nuclear material is in peaceful use.

An unambiguous condition to achieving a final accord that is meaningful in terms of nuclear proliferation safeguards is that Iran must take actions that allow the IAEA to comprehensively address the concerns about a military dimension to its nuclear programme in their entirety.

Practical Parameters of a Credible Nuclear Agreement with Iran

The report that follows offers a detailed examination of the necessities a credible deal presents as set out above. Practical key parameters suggested are as follows:

The Nuclear Programme and Facilities

- Iran must provide an expanded declaration on all aspects of its past and current nuclear programme. Iran's Natanz uranium enrichment plant is to have 2000-4000 operable IR-1 centrifuges. All excess centrifuges and cascade piping are to be removed for IAEA monitored storage. Its Fordow uranium enrichment plant is to be converted to a Research and Development installation, with infrastructure related to uranium enrichment removed. Iran's inventory of enriched uranium is to be brought below one metric ton of UF6, enriched up to 5% and the rest of enriched UF6 converted to uranium oxides, and shipped abroad for fuel manufacturing. The Arak reactor should be modified to operate as a light water research reactor by the replacement of some of the currently installed key nuclear components. Iran is required to verifiably declare all already manufactured centrifuge rotors and their components. Excess centrifuges and components will be subject to monitoring by the IAEA.

The Suspected Military Dimension of the Nuclear Programme

- Iran must allow the IAEA to address the whole picture of the military dimension concerns

and decommission, dismantle or convert to non-nuclear or peaceful use in a verifiable and irreversible manner nuclear related equipment, materials, facilities and sites that contradict the provisions of the safeguards agreement or the spirit of Article III of the Non-Proliferation Treaty (NPT). It must allow long-term monitoring of any installations previously involved in nuclear weapons research to ensure that the activities are not restored as an additional requirement.

The Non-Proliferation Safeguards Framework

- Iran must ratify and implement the Additional Protocol expeditiously as well as implement fully the verification and clarification requirements of the relevant resolutions of the IAEA Board of Governors and the UN Security Council. It must meet fully its obligations under the IAEA Statutes, Iran's Safeguards Agreement with the IAEA, including the modified Code 3 of the Subsidiary Agreements.

- Iran must provide information on the production source material, which has not yet reached the composition and purity suitable for nuclear fuel fabrication or for being isotopically enriched, including imports of such material. Iran will provide information on imports and domestic production of single and dual-use items listed in the guidelines of the Nuclear Suppliers Group.

- Iran must provide the IAEA with unconditional and unrestricted access to any and all areas, facilities, equipment, records, people, materials including source materials, which are deemed necessary by the IAEA to fulfill its requirements under the safeguards agreement, and to verify Iran's declarations made under the items above. These are needed both to understand the scope of the nuclear programme as well as address the possible military dimensions aspects. The purpose of these measures would be to re-establish Iran's non-proliferation records, and not to lay the basis for further punitive measures.

Timeline: 2002-2014

14 August 2002

The National Council of Resistance of Iran holds a press conference revealing that Iran is constructing an enrichment plant in Natanz and a heavy water production plant in Arak.

February 2003

An IAEA delegation led by Mohamed Elbaradei visits Natanz, and has discussions about the nuclear programme of Iran. The delegation acknowledges that Iran has failed in some of its reporting obligations under the NPT.

12 September 2003

The IAEA Board of Governors adopts a resolution calling for Iran to suspend all enrichment – and reprocessing – related activities.

21 October 2003

In an agreement struck between Iran and EU-3 foreign ministers (France, Germany, and the UK), Iran agrees to suspend its uranium enrichment activities, and ratify an Additional Protocol (AP). Iran agrees to provide the IAEA with a declaration on its past and current nuclear programme.

18 December 2003

Iran signs the AP, and starts its provisional implementation, which provides the IAEA with wider access to Iran's nuclear facilities.

February 2004

The IAEA finds out that Iran's declaration on its past nuclear programme had omitted references to work on more advanced, P-2, centrifuges.

18 June 2004

The IAEA Secretariat's report to its Board of Governors indicates that Iran failed to cooperate fully with IAEA inspectors. Iran restarts enrichment-related activities.

14 November 2004

Iran states that it will suspend enrichment-related activities following talks with the EU-3. According to the so-called Paris Agreement, Iran would maintain the suspension for the duration of talks with the EU-3. As a result, the IAEA Board of Governors decides not to refer Tehran's non-compliance with the terms of its safeguards agreement to the UN Security Council.

27 February 2005

Russia and Iran conclude a nuclear fuel supply agreement in which Russia would provide fuel for the Bushehr reactor.

8 August 2005

Iran resumes the production of uranium hexafluoride at its Isfahan uranium conversion facility, which halts negotiations between Tehran and the P5+1.

24 September 2005

The IAEA Board of Governors adopts a resolution finding Iran in noncompliance with its safeguards agreement. The resolution says that the nature of Iran's nuclear activities and the lack of assurance of their peaceful nature prepares the ground for future referral of the case to the UN Security Council.

4 February 2006	A special meeting of the IAEA Board of Governors refers Iran to the UN Security Council. The resolution calls upon Iran to suspend its uranium enrichment-related activities, reconsider the construction of the Arak heavy-water reactor, ratify the Additional Protocol and cooperate fully with the IAEA's investigations.
6 February 2006	Iran informs the IAEA that it will cease its voluntary implementation of the Additional Protocol.
11 April 2006	Iran announces that it has produced 3.5 percent enriched uranium at the Natanz pilot enrichment plant.
6 June 2006	P5+1 (China, France, Germany, Russia the United Kingdom, and the United States) propose a framework to Iran offering incentives for it to suspend its enrichment programme for an indefinite period of time.
31 July 2006	The UN Security Council adopts Resolution 1696, which calls for Iran to suspend enrichment-related and reprocessing activities for the first time.
23 December 2006	The UN Security Council unanimously adopts Resolution 1737, imposing sanctions on Iran for its failure to suspend its enrichment-related activities.
24 March 2007	The UN Security Council unanimously adopts Resolution 1747 in response to Iran's continued failure not to suspend uranium enrichment.
21 August 2007	The IAEA and Iran agree on a "Work Plan" for Iran to resolve long-standing questions about Iran's nuclear activities, which include possible work related to nuclear weapons development.
3 December 2007	The United States releases an unclassified summary of a new National Intelligence Estimate (NIE) report on Iran's nuclear programme. The NIE states that the intelligence community has judged "with high confidence" that Iran halted its nuclear weapons programme in the fall of 2003. The community assessed with moderate confidence that the programme had not resumed as of mid-2007.
3 March 2008	The UN Security Council passes Resolution 1803 broadening sanctions on Iran.
14 June 2008	The P5+1 present a new comprehensive proposal to Iran updating its 2006 incentives package. The new proposal includes an initial "freeze-for-freeze" process wherein Iran would halt any expansion of its enrichment activities while the UN Security Council agreed not to impose additional sanctions on Iran.
12 June 2009	Mahmoud Ahmadinejad wins the presidential election.
25 September 2009	US President Barack Obama, British Prime Minister Gordon Brown, and French President Nicolas Sarkozy announce jointly that Iran has been constructing a secret uranium enrichment facility at Fordow.

1 October 2009	The P5+1 and Iran agree "in principle" to a US-initiated, IAEA-backed, proposal to fuel the Teheran Research Reactor (TRR). The proposal entails Iran exporting substantial amount of its 3.5 percent enriched uranium in return for 20 percent enriched uranium fuel for the TRR. In the end, Teheran did not confirm the agreement.
9 February 2010	Iran begins the process of producing 20 percent enriched uranium for the TRR.
17 May 2010	Brazil, Iran, and Turkey issue a joint declaration trying to revive the TRR fuel-swap proposal. France, Russia, and the United States, however, reject the arrangement, citing Iran's larger stockpile of 3.5 percent enriched uranium and the failure of the declaration to address Iran's enrichment to 20 percent.
9 June 2010	The UN Security Council adopts Resolution 1929, which expands sanctions against Iran.
26 July 2010	The EU imposes further sanctions on Iran.
16 September 2010	The Stuxnet computer virus is first identified as a directed attack against an Iranian nuclear-related facility.
8 May 2011	Iran's Bushehr nuclear power plant becomes operational.
8 June 2011	Iran announces that it is increasing the rate of 20 percent enriched uranium production, also utilising the Fordow enrichment plant.
8 November 2011	IAEA report provides a detailed description of Iran's activities related to nuclear weapons development. The report notes that some weapons-related activities occurred after 2003.
January 2012	The EU bans all member countries from importing Iranian oil beginning 1 July 2012.
14 June 2013	Hassan Rouhani is elected president of Iran.
6 August 2013	President Rouhani calls for the resumption of serious negotiations with the P5+1 on Iran's nuclear programme.
26 September 2013	The P5+1 foreign ministers meet with Iranian Foreign Minister Mohammad Javad Zarif on the sidelines of the UN General Assembly meeting. The parties agree to meet again on 15 October in Geneva.
27 September 2013	President Barack Obama calls Iranian President Rouhani, which is the highest level contact between the US and Iran since 1979.

11 November 2013

IAEA Director General Yukiya Amano and Ali Akbar sign a Framework for Cooperation Agreement, which lays out initial practical steps to be taken by Iran within the following three months to provide access and information on heavy water production, uranium mines and research reactors planned to be built. The cooperation between parties is "aimed at ensuring the exclusively peaceful nature of Iran's nuclear programme through the resolution of all outstanding issues that have not already been resolved by the IAEA."

20-24 November 2013

Iran and the P5+1 meet in Geneva and, at the end, sign an agreement called the Joint Plan of Action. It lays out specific steps for each side in a six-month first-phase agreement, and the broad framework to guide negotiations for a comprehensive solution within the next six months.

12 January 2014

Iran and the P5+1 announce that they have agreed to begin the implementation of the Joint Plan of Action on 20 January 2014.

19 July 2014

Iran and the P5+1 announce that they will extend the talks through 24 November 2014.

I. Introduction

During the past year, Iran and the P5+1(China, France, Germany, Russia, the United Kingdom, and the United States) have continued extensive negotiations to craft a comprehensive nuclear agreement as a next stage to the Joint Plan of Action (JPOA) concluded in Geneva on 24 November 2013.[1] Parallel to that, the IAEA and Iran concluded on 11 November 2013 a Framework of Cooperation (FOC)[2] to address long outstanding questions regarding the scope and content of Iran's nuclear programme as requested, inter alia, by the United Nations Security Council.[3]

While Iran has kept to implementing the FOC and JPOA, the true test of arriving at a final deal would have to effectively address comprehensive concerns over its nuclear programme and commit Iran to significantly shrinking its programme's proliferation-sensitive aspects. This has proven to be a tough ride. Spiritual Leader, Ayatollah Khamenei, posted his redlines for the negotiations indicating inflexibility,[4] which may have prompted Mr Araqchi, the deputy Iranian nuclear negotiator, to state that according to the semiofficial Fars News Agency, a final agreement may not be possible by the envisioned deadline, 24 November 2014.[5] Moreover, as the Iranian Ambassador's recent letters[6] [7] to the IAEA demonstrate, Iran continues to challenge, inter alia, the Agency's right and obligation to verify the correctness and completeness of Iran's declarations on nuclear material and facilities under the Comprehensive Safeguards Agreement (CSA),[8] the legality of the IAEA Board resolutions, and the IAEA Secretariat's practices over reporting its findings to the IAEA Board and the UN Security Council. At the same time, Iran has continued to fail to meet agreed upon deadlines to provide answers to the IAEA's questions regarding some of the military aspects of its nuclear programme.[9]

Due to the fact that Iran has been running parts of its nuclear programme first clandestinely and then without satisfactorily fulfilling its reporting obligations to the IAEA and additionally disregarding UN Security Council resolutions, the onus of proof bears heavily on Iran to show that its nuclear programme is entirely peaceful. Both Iran and the P5+1 recognise that this is a time consuming process. Building the international community's confidence about the scope of the programme and Iran's compliance with its undertakings will take many years. To get through this process, the P5+1 has taken a huge step in allowing for some enrichment in Iran but in a manner that effectively addresses proliferation concerns and prevents a 'breakout' scenario. Breakout for Iran's case is a term taken to mean the point at which Iran could dash to produce enough weapon-grade uranium (or separated plutonium) for one bomb in a manner that the IAEA or a Western intelligence service would be unable to detect and respond to in time.

1. Communication dated 27 November 2013 received from the EU High Representative concerning the text of the Joint Plan of Action, IAEA, INFCIRC/855, 27 November 2013.
2. Joint Statement on a Framework for Cooperation, GOV/INF/2013/14, IAEA, 11 November 2013.
3. United Nations Security Council Resolution 1929, 9 June 2010.
4. Khamenei issues 'red lines' ahead of nuclear talks, Al Arabiya, 9 October 2014.
5. Paul Richter, Iran nuclear talks may be extended, The Stars and Stripes, 11 October 2014.
6. Communication dated 4 June 2014 received from the Permanent Mission of the Islamic Republic of Iran to the Agency regarding the Report of the Director General on the Implementation of Safeguards in Iran, IAEA, INFCIRC/866, 13 June 2014.
7. Communication dated 19 September 2014 received from the Permanent Mission of the Islamic Republic of Iran to the Agency regarding the Report of the Director General on the Implementation of Safeguards in Iran, IAEA, INFCIRC/868, 2 October 2014.
8. The Text of the Agreement between Iran and the Agency for the Application of Safeguards in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons, INFCIRC/214, 13 December 1974.
9. Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council Resolutions in the Islamic Republic Iran, GOV/2014/43, IAEA, 5 September 2014.

During the period under the comprehensive agreement when the IAEA proceeds with verifying the correctness and completeness of Iran's declarations, Iran is expected to continue with some enrichment but under a different scope, alongside defined parameters with practical limits, and reinforced with transparent measures. This means that Iran will have to significantly scale down and remove features that will allow Iran to retain a breakout to nuclear weapons within a relatively short timeframe that remains under a year.

In addition to defining the scope and parameters of how a comprehensive nuclear deal with Iran will look, i.e. elements allowed and those not allowed, a lot of the devil is in the detail in terms of the technicalities and definitions. To ensure the sustainability of such a deal, a number of interlocking and mutually-supporting elements should be in place to ensure the credibility and durability of a comprehensive agreement.

When allowing Iran to retain some portion of its enrichment programme, the comprehensive agreement should have the following features to provide additional assurances that Iran's nuclear programme is and remains peaceful:[10]

- A well-defined nuclear programme meeting practical needs
- An effective verification regime
- Adequate irreversibility of constrains with early detection of violations
- Sufficient response time in case of violations
- Verifiable dismantlement of elements related to military dimension

This paper will focus on the verification aspects of elements needed in a comprehensive nuclear agreement with Iran. The paper also recommends practical parameters for Iran's uranium enrichment and heavy water reactor programmes. Suggestions are based on the implementation of the CSA, and relevant UN Security Council resolutions on Iran, recent experiences from the implementation of the JPOA and JOC, and complemented with on-the-ground experiences from the IAEA's verification activities in South Africa after its dismantlement of its nuclear weapons programme, and other proliferation cases in Libya, Syria, and North Korea.

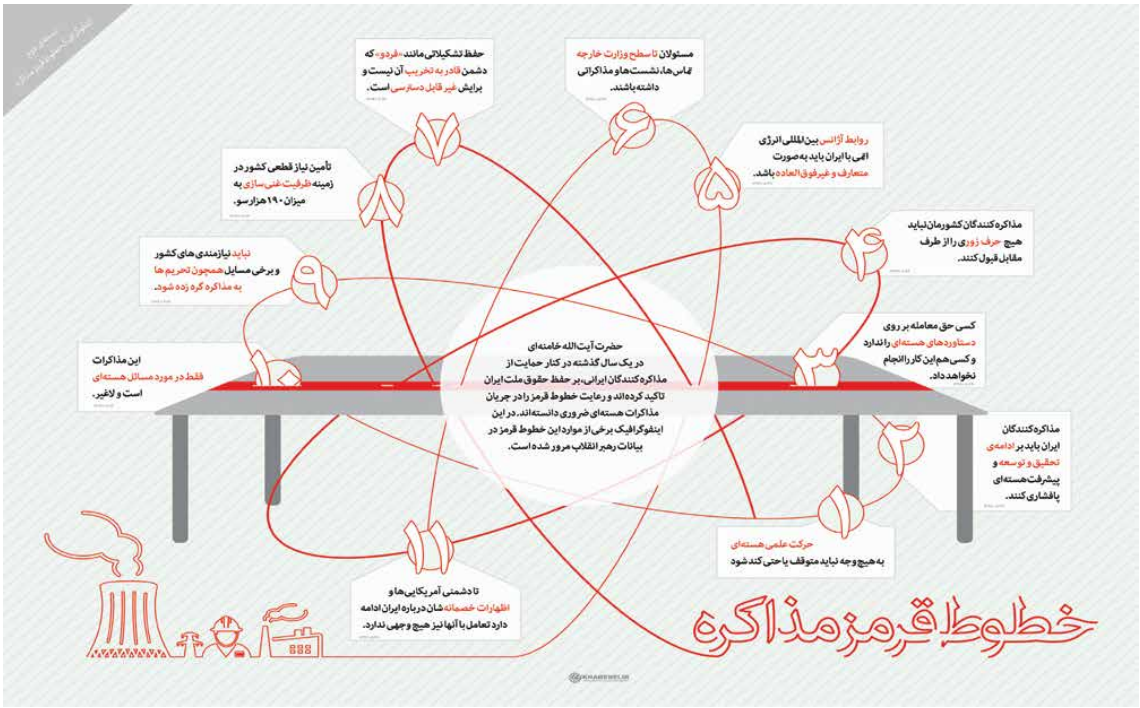
10. D. Albright, O. Heinonen, and A. Stricker, "The Six's" Guiding Principles in Negotiating with Iran, ISIS, 3 June 2014

II. Defining Practical Needs

During the last two decades Iran has been building infrastructure for the front end of the nuclear fuel cycle, which is described in more detail in the Annex.

In constructing the parameters under which Iran retains a civilian nuclear programme but addresses proliferation concerns, the basis to operate on must be to recognise that we do not have a full picture of the programme. For instance, the number of centrifuges operating in Natanz and Fordow are well known, but the IAEA has not been able to establish a full inventory of all types of centrifuges manufactured in Iran, and their current location. Similarly, the IAEA has been able to verify the declared inventory of uranium in Iran, but it has not been permitted to verify completeness of Iran's declaration of nuclear material, i.e. all nuclear material and facilities have been placed under safeguards. The IAEA's concerns about Iran's nuclear weapons related research and development (R&D) remain unresolved. Due to these unknowns, there will be uncertainties. Therefore, the technical parameters will have to be crafted to limit ambiguities to a minimum. Agreeing to a higher number of centrifuges in Natanz, and compensating the breakout time with a smaller declared enriched uranium inventory is, as an example, not a credible solution when the total amount of uranium in Iran remains unverified and types and inventories of centrifuges are not known.

Still, achieving a mutually-agreed understanding on the future parameters of Iran's nuclear programme will be difficult, since the Spiritual Leader, Ayatollah Khamenei, has publicly set Iran's red lines for an acceptable solution, most recently on his website.[11] These red lines include, inter alia, the following technical requirements:



(Credit: khamenei.ir)

Fig 1. Red lines defined by Ayatollah Khamenei[12]

11. As Deadline Nears, Khamenei Lays Out Impossible Red Lines for Nuclear Talks, The Algemeiner, 12 October 2014.

12. 'Iranian infographic on negotiations', *Khamenei.ir*, undated.

- The "nuclear science movement should not come to a halt or even slow down."
- The "Iranian delegation should insist on continuing nuclear research and development."
- "No one has the right to bargain over nuclear achievements and no one will do so."
- "Our delegation should not accept any impositions from the other side."
- "Protecting an organisation like Fordow which the enemy is not able to destroy and is inaccessible to them."
- "Supplying the final needs of the country's enrichment capacity, which is 190 thousand SWUS" (separative work units for uranium enrichment).
- "Basic needs of the country and some issues like the sanctions should not be tied to the nuclear talks."

Iran justifies its uranium enrichment capacity – 190000 SWUs[13] – with the need to provide fuel for its Bushehr reactor.[14] However, the position of needing to produce its own fuel has to be measured against the technical realities, which are against this assertion. Without extensive outside assistance in the form of key equipment, raw materials and advanced technology, Iran has limited capabilities for running that many IR-1 centrifuges or an equivalent number of advanced centrifuges to fuel the Bushehr reactor over the next decade or two. It will need to continue relying on importing fuel from Russia or another major supplier noting also that there is globally more than enough nuclear fuel fabrication capacity. Furthermore, we need to keep in mind that Iran has not demonstrated the requisite technical ability to produce fuel of sufficient quality to ensure the safe operation of Bushehr.

To be independent from foreign fuel supplies, Iran needs uranium, but its own known uranium resources are modest and are sufficient to cover only the annual reloads for a single Bushehr type reactor for up to five years (see Annex). In this sense, building of domestic light water reactor fuel capacity does not contribute to nuclear energy independence and is unlikely to be economically justifiable.

Hence, limiting Iran's centrifuge programme to between 2,000 and 4,000 IR-1 centrifuges is consistent with Iran's actual needs for enriched uranium for many years.[15] Even with 2,000 IR-1 centrifuges, Iran would still have sufficient enriched uranium for its existing and foreseen research reactor needs.

Retaining the above-stated number of centrifuges in Iran would not satisfy the ideal scenario, which is to have no enrichment programme in Iran. But current discussions are now at a different juncture. This means looking at how Iran can still retain a nuclear programme, but without the capabilities that allow it to build a bomb at its discretion. In other words, addressing "breakout"[16] times should Iran decide to leave the agreement or chip away at the agreed-upon parameters.

13. Annual reload of a Bushehr reactor requires about 130000 SWU enrichment effort. Normally SWU is given in kgU/year, but Iran could also be using kgUF6/year as a unit here. Another possibility is that the SWU figure cited by Iran includes not only the needs of Bushehr, but also the requirements of the planned Darkhovin power plant and research reactors. This would mean, if IR-1 centrifuges are to be used, construction of an additional enrichment facility or using mainly IR-2m centrifuges in Natanz.

14. Bushehr is a 930 MWe light water reactor located at the Gulf, which was constructed by a Russian company and completed in 2011. The contract with the Russians includes delivery of nuclear fuel until 2021 with options for further deliveries upon agreement.

15. Defining Iranian Nuclear Programs in a Comprehensive Solution under the Joint Plan of Action, ISIS, 15 January 2014.

16. Breakout time is the time required to produce enough weapons grade uranium (WGU) for one or more nuclear weapons. The amount of WGU needed for a nuclear weapon is one significant quantity (SQ), which is commonly defined as 25 kilograms of 90 % enriched uranium.

III. Options in Reducing Enrichment Capacity

One of the challenges for the negotiators will be what to do with the already installed 18000 IR-1 centrifuges in Natanz and Fordow, and 1000 IR-2m centrifuges in Natanz. A recent *New York Times* article purported that the parties are discussing the disconnection of centrifuges to reduce enrichment capacity.[17] There are substantial technical distinctions between merely disconnecting centrifuges, disabling the feed pipes to these centrifuges, or entirely removing the centrifuges and piping from the facility.

Since Iran started larger-scale uranium enrichment at Natanz in 2007, it has installed approximately 5,000 new centrifuges per year during peak periods. This effort has included assembling centrifuge rotors; installing rotors into casings; and laying cables for control electronics, piping for cooling of centrifuges, and the piping for feed and withdrawal of uranium hexafluoride gas to each individual centrifuge.

There are three possible scenarios to follow:

- The first and simplest scenario is just to disconnect centrifuges from the uranium gas feed lines, which can be reversed in a matter of a week. Since all necessary infrastructure together with centrifuges remains in place, such a step is considered to be a relatively straightforward reversible scenario.
- The second option is to remove most of the cascade feed and withdrawal piping from all but one cascade unit (leaving in 3,000 IR-1s operable in Natanz). In this option, all 18000 IR-1 and 1000 IR-2m centrifuges remain installed along with some piping to ensure that they can be kept in vacuum to avoid corrosion. Again, since significant part of the infrastructure remains in place, reinstallation of the dismantled piping for IR-1 and IR-2m centrifuges could be done in a couple of months.

(Credit: IRIB Iranian TV)

Fig 2. IR-2m centrifuge cascade in Natanz[18]

17. David Sanger, "U.S. Hopes Face-Saving Plan Offers a Path to a Nuclear Pact With Iran," *The New York Times*, September 19, 2014. (http://www.nytimes.com/2014/09/20/world/middleeast/us-hopes-face-saving-plan-offers-a-path-to-a-nuclear-pact-with-iran-.html?_r=0)

18. 'IR-2m centrifuge cascade in Natanz', *IRIB Iranian TV*, February 2012.

- A third and more comprehensive and irreversible option is to remove all excess centrifuges and cascade piping (above 2000-4000 operable IR-1 centrifuges in Natanz) from the enrichment plants in Natanz and Fordow and have them stored under IAEA monitoring. This would push reinstallation and reconnection times to beyond six months (for example, if 15,000 IR-1 and 1000 IR-2m centrifuges including their cascade piping were removed).

However, all these approaches have a fundamental weakness. Since the IAEA has not had full access to the sites where Iran manufactures centrifuges, it does not know the total inventory of centrifuges available today to Iran. This then leaves Iran with the option to replace the centrifuges and cascade piping that has been removed, by installing a smaller number of IR-2ms instead of IR-1 centrifuges. For example, if Iran were to reinstall 3,000 IR-2ms instead of 15,000 IR-1s (based on a SWU ratio of 5:1), this would cut reinstallation times back down to two to three months. Such a time interval is short in responding to a possible Iranian breakout scenario.

There are additional parameters and variables to be considered and implemented to ensure adequate irreversibility of Iran's enrichment capacity, which go beyond the number of centrifuges installed and push breakout times beyond one year. In other words, even the removal of excess centrifuges and piping would not be enough without other steps to limit Iran's enrichment. Accountability of centrifuge components is one example for the reasons stated above. Iran has reached an industrial capacity to produce centrifuge rotors although it may be facing some limitations due to a lack of key raw materials. All the already-manufactured centrifuge rotors and their components would have to be fully disclosed, completeness of that inventory verified as extensively as is possible and the excess centrifuges should be subject to monitoring by the IAEA.

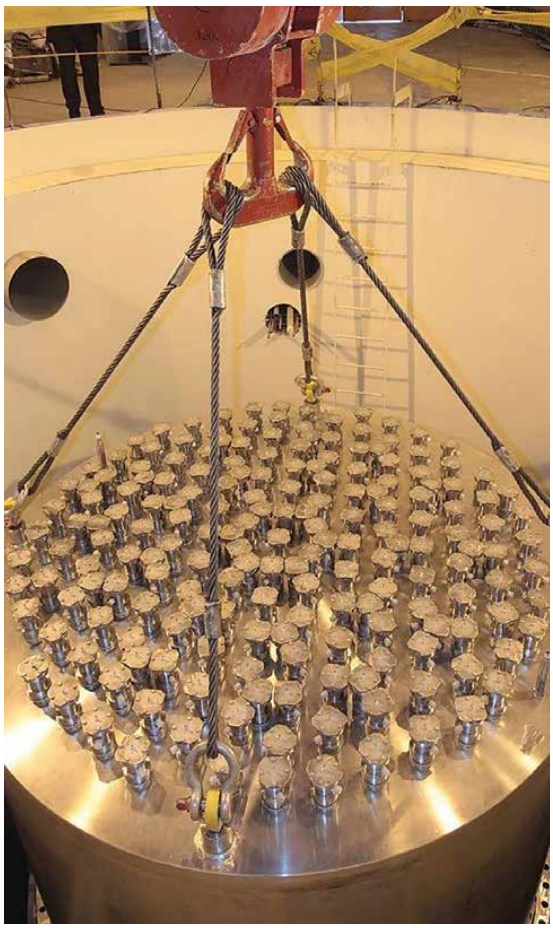
Another important parameter to consider is the inventory of enriched uranium. Iran currently has roughly 7.7 tons of low-enriched uranium as UF6 gas, which is sufficient to produce weapons grade uranium for 4-5 nuclear devices, if further enriched. Thus the inventory of enriched uranium would need to be brought below one metric ton of UF6 enriched up to 5% and the rest of enriched UF6 converted to uranium oxides, and shipped abroad for fuel manufacturing. Iran did agree tentatively to such an arrangement in 2009 as part of the Teheran Research Reactor fuel deal with the United States, France and Russia.[19] In addition, Iran should commit to not having a processing line to reconvert uranium oxide back into UF6.

There have also been proposals to permit Iran to have a higher number of operable IR-1 centrifuges, but reduce the amount of enriched UF6 in Iran to a few hundred kilograms, which would lengthen the breakout time. However, the shortcoming of such an approach is the fact that the IAEA has not yet been able to confirm the completeness of Iran's declarations on nuclear material, and also the total number of manufactured centrifuges in Iran remains unknown. Such an approach moreover opens the door for a hedging scenario where Iran could slowly increase the inventory of enriched UF6 - e.g. citing technical difficulties - with conversion of UF6 to oxides. Iran could then breakout using known and unknown UF6 inventories.

19. IAEA Receives Initial Iranian Response on Proposal to Supply Nuclear Fuel to Research Reactor, IAEA Press Release, 29 October 2009. (http://www.iaea.org/newscenter/pressreleases/2009/prn200914.html).

IV. Replacement of the Arak Heavy Water Reactor

It is understood in arms control that perfect irreversibility may not be possible but that in practice the restoration of the previous, unconstrained situation should take a long time – an order of years and not months. In the case of Iran, a long-term agreement would have little lasting value if Iran can reverse the constraints in a matter of days or months. The case of North Korea contains many examples in considering the approach. North Korea shut down its large gas-graphite reactor, ending its ability to produce weapon-grade plutonium, as a part of the 1994 US/DPRK Agreed Framework. When this agreement ended in 2002, North Korea was able to reestablish fairly quickly its small plutonium production capability, which culminated in its first nuclear weapon test in 2006. After 2009, North Korea has put the reactor in operation again after reconstruction of the cooling system for the reactor, which had been demolished in 2007 as part of the agreement reached in the Six Party Talks.[20]



(Credit: president.ir)

Fig 3. Installation of a calandria to the Arak heavy water reactor[22]

Irreversibility is the core of the dispute about Iran limiting plutonium production in the Arak nuclear reactor, where construction has proceeded already to a stage where key nuclear components are being manufactured and installed. Such a heavy water reactor can with its current design produce enough weapon-grade plutonium for up to two nuclear weapons per year. Iran has suggested reducing plutonium production in this reactor by using enriched uranium rather than natural uranium. Some scientists[21] have also suggested in addition lowering the power of the reactor. These proposals, taken in combination, would reduce plutonium production to a fraction of the current value, but regrettably, these suggested design changes are fairly reversible. Iran would still be able to restore the capability to produce annually significant amounts of weapon-grade plutonium without too much difficulty. A more proliferation-proof approach is to remove the currently installed core and replace it with a smaller one not able to hold enough natural uranium for the reactor to work. Iran so far resists this proposal.

20. D. Albright and S. Kelleher-Vergantini, Yongbyon: Centrifuge Enrichment Plant Expands while 5 MWe Reactor is Possibly Shut Down, ISIS, 3 October 2014.

21. A. Ahmad, F. von Hippel, A. Glaser, and Z. Mian, A Win-Win Solution for Iran's Arak Reactor, https://www.armscontrol.org/act/2014_04/A-Win-Win-Solution-for-Irans-Arak-Reactor.

22. 'Heavy-water reactor at Arak plant', *Presstv.ir*, June 2013.

With the above changes to the Arak reactor, there would also be no need for heavy water production. The heavy water could be shipped out and sold on the international market. This step would further make the Arak reactor changes reasonably irreversible, since the production capacity of the heavy water plant in Arak is 15 tons of heavy water annually. It would take about five years to produce enough heavy water for a reactor now being at final stages of construction in Arak.

Iran has stated that it does not have a reprocessing plant, which is essential to recover plutonium from the spent fuel. Construction of a small reprocessing plant could be difficult to detect.[23] Therefore, it is essential that Iran provides a detailed account of its work on the PUREX reprocessing scheme including a detailed explanation on its attempts to acquire heavy-duty manipulators and lead-shielded windows for the hot cells and that effective export controls are in place and enforced.[24]

In the case of Iran, a long-term agreement would have little lasting value if Iran can reverse the constraints in a matter of days or months.

23. M.D. Zentner, G.L. Coles and R.J. Talbert. Nuclear Proliferation Technology Trends Analysis, PNNL-14480, September 2005

24. Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council Resolutions 1737 (2006), 1747 (2007) and 1803 (2008) in the Islamic Republic Iran, GOV/2008/15, IAEA, 25 May 2008.

V. Effective Verification

One of the key aspects in ensuring that any comprehensive deal is being adhered to and properly implemented is having in place an effective detection, verification and monitoring presence over Iran's nuclear programme. Effective verification should be a non-negotiable basis by which a deal can hold the best promise in terms of credibility and durability. The IAEA must be able to provide prompt warning of violations, determine the correctness and completeness of Iran's declarations, establish the total number of centrifuges produced by Iran and the size of its natural and enriched uranium stocks, and establish confidence in the absence of undeclared nuclear activities or facilities, including providing assurances on the absence of nuclear weapons-related activities in Iran.

Iran has, however, in the course of its dealings with the IAEA refused to concede easily in this area even under conditions with less demanding safeguards. In its letters to the IAEA, Iran has challenged the IAEA's right under the CSA to verify the correctness and completeness of a state's declarations. Under the CSA, Iran, like other countries, is committed to submit all nuclear material in their territory under IAEA safeguards. Between 1991 and 1993 the IAEA Board of Governors and the General Conference undertook a number of decisions to ensure that in a state with a CSA, no nuclear material – declared or undeclared – is diverted for nuclear weapons or purposes unknown. The application of this strengthened verification regime has since been applied across the board. And in cases of proliferation concern such as South Africa,[25] North Korea,[26] Libya[27] and including Iran, the IAEA Board has been specific in its request to verify the correctness and completeness of their declarations. Despite the Board's re-affirmations, Iran continues to challenge this interpretation.

Even with a basic CSA in place, Iran's refusal to acknowledge the correctness and completeness understanding means that safeguards can only remain limited. This is all the more so deficient in light of the past couple of decades where Iran has not fulfilled its reporting obligations with regard to its inventories on nuclear material and facilities. Not reporting receipts of two tons of various uranium compounds from China, processing further of yellow cake received from South Africa and other sources are classic examples of its diversion of nuclear material.

The strength of the IAEA verification system is access to nuclear material, facilities, equipment and people. To this end, the IAEA has, under its Comprehensive Safeguards Agreement and Additional Protocol (AP), significant tools available if fully implemented and utilised. Iran argues that ratifying the Additional Protocol is enough but while such a step is welcome, it is not sufficient for what is required in a comprehensive agreement. The long-term agreement must establish a range of other verification provisions, or an Additional Protocol Plus.

Throughout the long history of discussions, Iran has often offered 'transparency' to build international confidence for its nuclear programme. Recently President Rouhani has again publicly stated Iran's readiness for greater transparency. More importantly, such transparency should be understood and implemented in a meaningful and systematic way. Even in the name of 'transparency,' where Iran decides to 'show' a place previously off-limits (imposed by Iran),

25. South Africa's Nuclear Capabilities, GC(XXXV)/RES/567, IAEA, 20 September 1991.

26. Report by the Director General on the Implementation of the Resolution Adopted by the Board on 25 February 1993 (GOV/2636) and of the Agreement between the Agency and the Democratic People's Republic of Korea for the Application Safeguards in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons (INFCIRC/403).

27. Implementation of the NPT Safeguards Agreement of the Socialist People's Libyan Arab Jamahiriya, paragraph 5, GOV/2004/18, IAEA, 10 March 2004.

Accomplishing adequate verification, including the IAEA establishing that Iran's programme is exclusively peaceful, will take many years.

such inspection visits can have meaning only if substantially new information and discussions take place, and explanations are provided on the scope and content of the nuclear programme. Hence openness should be clearly defined and become a legally-binding undertaking, and not treated as good will visits to be granted when problems arise.

To minimise further the effects of the unknowns, it is important to understand the historical production and acquisition of uranium and its compounds by Iran. As part of the information obtained from the Iranian mines and milling facilities under the FOC, Iran has provided information on uranium production of mines in Gcchine and Ardakan. It is important that the IAEA shares those actual numbers, and whereabouts of those materials with its member states, which may have additional information to complement the statements made by Iran. This would also provide the member states indications on Iran's compliance with its undertakings. Releasing of such information by the IAEA will not jeopardise its independent assessment of Iran's declarations, but will complement information available.

Going further, according to the provisions of the CSA, a state has to declare all nuclear material in its territory. Thus military sites do not form sanctuaries, but the IAEA has the right to conduct inspections on those under a CSA and complementary access under an AP, when appropriate. Iran has to provide the IAEA with unconditional and unrestricted access[28] to any and all areas, facilities, equipment, records, people, materials including source materials, which are deemed necessary by the IAEA to fulfill its requirements under the safeguards agreement, and to verify the correctness and completeness of Iran's declarations. These are needed both to understand the scope of the nuclear programme as well as address the possible military dimensions aspects of it.

Accomplishing adequate verification, including the IAEA establishing that Iran's programme is exclusively peaceful, will take many years. Just as an example, with medium-sized nuclear programmes in European countries with CSA and AP implemented, it took the IAEA about five years to conclude that all nuclear material in these countries was in peaceful use. The duration of an agreement up to 20 years is reasonable in light of the two decades of Iran's non-compliance with its safeguards obligations and non-cooperation with the IAEA.

A comprehensive agreement should also take the opportunity to assess the usefulness of strengthening certain linkages. For instance, the Sanctions Committee on Iran that was established under UNSC's resolution 1737[29] is a separately run mechanism from the IAEA verification process. At a minimum, these two bodies could be allowed to share relevant information. It might also be reasonable to consider whether monitoring the implementation of sanctions should be assigned to a special unit to be established within the IAEA.

Adequate verification also requires Iran to verifiably stop its efforts to procure key proliferation-sensitive goods illegally for its nuclear programmes. If not stopped, Iran could secretly purchase

28. Due to the nature of the verification and monitoring, such access should be done on short notice at, inter alia, centrifuge assembly and component manufacturing plants and at enrichment facilities.

29. United Nations Security Council Resolution 1737, 23 December 2006.

the wherewithal for secret nuclear sites or activities. This requires a continuation of national and UN Security Council sanctions on proliferation-sensitive goods for the long term. However, an agreement will need to eventually allow for monitored Iranian purchases for its legitimate nuclear programmes and civilian industries while ensuring that Iran is not buying goods illegally for banned activities.

Another important factor is the financial and human resources of the IAEA. In order to meet the verification requirements, the IAEA needs additional expertise on sensitive technologies. The arrangements have to be made that this staff also has access to Iranian facilities and can participate in discussions with Iranian experts. Such arrangements worked well in South Africa, and Libya, where the IAEA used its additional experts as well as inspectors designated under the CSA.

To ensure that the IAEA gets the necessary legally-binding authorities to conduct the additional verification work indicated above, it is recommended that the UN Security Council endorses the agreement between P5+1 and Iran.

VI. Enhanced Reporting by the IAEA

In its letters to the IAEA, Iran states that the Agency should strictly observe its obligations under Article VII.F of the Agency's Statute, which stipulates that the Agency and its staff shall not disclose any industrial secret or other confidential information coming to their knowledge by reason of their official duties for the Agency.[30] Furthermore, the letters refer to Article 5 of the CSA,[31] which stipulates that the Agency shall take every precaution to protect commercial and industrial secrets and other confidential information coming to its knowledge in the implementation of this Agreement. However, while according to the CSA the Agency shall not publish or communicate to any State, or organisation any information obtained by it in connection with the implementation of the CSA, it makes the exception that specific information relating to the implementation thereof may be given to the Board of Governors of the Agency to the extent necessary for the Agency to fulfill its responsibilities in implementing this Agreement. Taking into account the latter, and the fact that Iran has not heeded to the UN Security Council resolutions to suspend its enrichment, reprocessing, and heavy water related activities, it is important that the IAEA Secretariat describes the actions taken – adherence as well as violations - of Iran in quantitative ways such as disclosing inventories of nuclear material produced and number of centrifuges installed or operating.

In this regard, the IAEA Director General's reports on Iran that focus on the details and their comprehensiveness, is not contrary to issues of confidentiality but instead seen as required to allow states to judge for themselves the situation in Iran and its compliance with the undertakings.

30. The Statute of the IAEA. http://www.iaea.org/About/statute.html

31. The Text of the Agreement between Iran and the Agency for the Application of Safeguards in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons, INFCIRC/214, 13 December 1974.

VII. Resolving Questions Related to the Military Dimension

Iran's most serious verification shortcoming remains its unwillingness to address the IAEA's concerns about the past and possibly on-going military dimensions of its nuclear programmes. For the IAEA to conclude that all nuclear material is in peaceful use, Iran must satisfy the IAEA in this key area.

There are reports that much of the nuclear weapons related work by the military institutions came to halt in 2003. At the same time, the IAEA has assessed in its reports that some of this R&D has continued since. It is important to understand the status of Iran's PMD efforts, noting that one of the last duties of Iranian personnel and organisations involved was to document work done. One plausible reason for such effort could have been to save information for further use. Unless properly addressed, it would be difficult to create a meaningful and robust verification regime for Iran. Such additional long-term monitoring took place in South Africa from 1993 until 2010 until the IAEA was able to conclude that all nuclear material in South Africa was in peaceful use. Otherwise, it would also render difficult for the IAEA to determine with confidence that any nuclear weapons activities are not ongoing – a necessary ingredient for a long-term deal.

(Credit: Digital Globe via ISIS)

The list of IAEA questions on the PMD is long. While the recent FOC agreement between Iran and the IAEA is welcome, the process is far from over. Many of the issues on the list above are interconnected, and they cannot be solved in isolation and not through the step-by-step process. In other words, there should be an understanding and actions provided by Iran that allows the IAEA to address the whole picture of the military dimension concerns. That should be an unambiguous condition to achieving a final accord that is meaningful in safeguards terms.

Fig 4. High explosives test chamber in Parchin[32]

32. 'Status of Alleged High Explosive Test Site at Parchin Military Complex, August/November 2013', ISIS, May 2014.

The agreement should also have provisions to ensure that Iran will decommission, dismantle or convert to non-nuclear or peaceful use in a verifiable and irreversible manner, nuclear related equipment, materials, facilities and sites that contradict the provisions of the safeguards agreement or the spirit of Article III of the NPT. Such installations will be subject to long-term monitoring by the IAEA.

Finally, limiting nuclear capabilities at known sites does not make sense if at the same time the deal makes it easier for Iran to make weapon-grade uranium at military sites. The comprehensive agreement must focus on both potential pathways as necessary for adequate verification to be carried out.

VIII. Adequate Response Time

An agreement must provide sufficient time to mount an effective response to major violations by Iran. There are two parts to this principle-one involves intrusive and effective IAEA inspections able to promptly detect and report non-compliance and the other recognises that even the most intrusive inspections are alone inadequate to provide enough response time in the case of Iran. The latter's adequate response time requires significant limitations on content and parameters of Iran's nuclear programme and translates into a need to limit Iran's pathways to making nuclear weapons.

IAEA reports form a key part of the monitoring of compliance from the point of view of P5+1 and the international community. The member states can use these reports to complement their findings from their activities conducted by national means. From a practical point of view, the quarterly reporting on progress and findings by the IAEA should be sufficient. However, the IAEA should consider releasing factual information as it becomes available. Timeliness of conclusions depends on several parameters. This would entail the detection of the event, asking for clarification and additional sampling.

Much of that depends on the cooperation of the inspected party, but also on the event itself. While diversion of declared material is easily detectable, some more sophisticated events may take longer to detect. The IAEA's practice is to review each finding and claim meticulously, spending a fair amount of time and resources to refute or confirm them. Revised explanations provided by the inspected state also slow down the IAEA. This process needs to be re-thought. The IAEA verification system has its technical limitations. One of the tools the IAEA uses is environmental sampling, which has resulted in long in-between lead times. The latest IAEA report to its Board of Governors indicated that the environmental sample analysis results for Natanz FPEP, FEP, and Fordow were from 28 January 2014, 5 February 2014, and 28 January 2014, respectively.[33] If additional samples and clarifications are required, the results will in practice take six months. The IAEA work process needs to be factored into an overall understanding of timeliness of response.

An effective metric of adequate limits on Iran's main overt pathway to nuclear weapons, its centrifuge programme, is breakout time, which measures the length of time Iran would need to produce enough weapon-grade uranium for a single nuclear weapon. This technical breakout value is converted via detailed breakout calculations into an equivalent number of centrifuges that would be installed in Iran, which results in an oft-stated limit of about 2,000-4,000 IR-1 centrifuges remaining in Iran as part of a comprehensive deal.

There are other reasons to make known breakout times longer. In the past, Iran has conducted activities, and concealed them in such ways that were not quickly detected or stalled in allowing the IAEA to proceed with its investigations. Achieving the necessary evidence to judge with high confidence that violations have indeed occurred is time consuming and intelligence reliant in key cases, such as the discovery of the once covert Natanz and Fordow Fuel Enrichment Plants, clandestine centrifuge R&D at Kalaye Electric, and black market nuclear related imports including imports of nuclear material, some with possible military uses.

There is also the still unresolved file on the development of nuclear weapons. The IAEA has not yet been able to verify that Iran has submitted all its nuclear material under IAEA safeguards. Moreover, a larger programme also makes it easier for Iran to hide illicit foreign procurements,

33. IAEA, "Implementation of the NPT Safeguards Agreement and Relevant Provisions of Security Council Resolutions in the Islamic Republic of Iran," GOV/2014/28, 22 May 2014.

some of which could be slated for a clandestine programme. To this end, it is crucial that Iran reports all imports and manufacturing of single and dual use items regardless of whether the end user is the nuclear programme and provides the IAEA access to that information and those items.[34]

While breakout time does not include the total time to produce a nuclear weapon for testing underground or mounting on a missile, the production of the weapon-grade uranium is the more difficult and time-consuming portion of making a nuclear weapon. Once Iran has enough weapon-grade uranium for a weapon, the material would ostensibly vanish to covert sites for further weaponisation efforts, which could be small in size without visible detectable signatures as it was in the case of South Africa. An additional concern is the fact that Iran may have received a sufficient amount of design information to avoid testing. If a gun-type nuclear device is a goal, it requires more material, but there is no need for testing. Thus, the priority must be to limit Iran's ability to first produce the weapon-grade uranium.

A durable comprehensive deal over Iran's nuclear programme cannot be reached without elements to show that Iran has cut off its path to a bomb. It would create an inherently unstable situation. The parameters outlined above aim to address proliferation concerns that at the same time allow for a limited nuclear programme in Iran.

Once Iran has enough weapon-grade uranium for a weapon, the material would ostensibly vanish to covert sites for further weaponisation efforts, which could be small in size without visible detectable signatures as it was in the case of South Africa.

34. Olli Heinonen, Testimony on 'Verifying Iran's Nuclear Compliance', The United States House Committee on Foreign Affairs, 10 June 2014.

Annex: Further Background on Iran's Nuclear Programme

1. History

Iran's nuclear programme originates from the late 1950s. Like many countries developing nuclear energy, Iran acquired a research reactor from the US in the 1960s and established a nuclear research centre in the outskirts of Teheran. In the 1970s the Shah of Iran launched an ambitious programme to construct 23 nuclear power reactors within two decades. His plans also included building nuclear fuel cycle facilities such as uranium enrichment and spent fuel reprocessing. The US government had, from the beginning, proliferation concerns regarding the aspirations of Iran, and suggested instead that Iran participate as an investor in uranium enrichment in the US, and that it build a multinational reprocessing plant in Iran,[35] or possibly jointly in Pakistan.[36] Although Iran participated in uranium enrichment ventures in France, signed contracts for construction of nuclear power plants with German and French companies, it slowly started to build its own nuclear fuel cycle capacities by initiating R&D, inter alia, on uranium laser enrichment.[37] Before the revolution, Iran had also signed contracts with a South African company for more than 10,000 tons of yellow cake to be used as a raw material for its nuclear fuel cycle activities.

The 1979 Islamic Revolution, however, brought all the nuclear construction and R&D activities to a halt in Iran. In the mid-1980s – when Iran was at war with Iraq – Iran decided to revive its nuclear programme. The efforts to acquire nuclear power and fuel cycle technology from Germany, France, Brazil, Argentina and Spain, were blocked by the US.[38] This lead Iran to turn to China, which provided research reactors to the newly established Isfahan Nuclear Technology Center, large-scale uranium conversion technology and support for the emerging laser-enrichment programme and nuclear materials. Iran concluded contracts not only to finish the construction of the power plant at Bushehr and for the acquisition of uranium laser enrichment technology, but also to acquire a gas centrifuge enrichment plant and a heavy water reactor from Russia. The uranium enrichment efforts and the heavy water reactor related activities were blocked by the US.

35. National Security Decision 292, National Security Council, Washington DC, 22 April 1975.

36. The Deputy Secretary of State, Memorandum for the Assistant to the President for National Security Affairs, 18 April 1975.

37. G. Robert, Iran's Deal with L.A. Firm Widens Nuclear Capability, Los Angeles Times, 22 August 1979.

38. Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions 1737 (2006) and 1747 (2007) in the Islamic Republic of Iran, paragraphs 4-7, GOV/2007/58, IAEA,15 November 2007.

2. Nuclear Fuel Cycle

(Credit: IAEA, AREVA, Cameco, Fortum, Posiva, TVO, WNA)

Fig 5. Nuclear fuel cycle[39]

Mining: Saghand and Gacchine
In Iran uranium ore is mined from uranium mines, but it can also be a by-product of copper, phosphate or gold mining.

Milling/Refining : Ardakan and Gacchine
Removal of impurities from the ore to produce yellow cake (uranium concentrate).

Conversion: Esfahan
Conversion of yellow cake into uranium dioxide (UO2) or hexafluoride (UF6).

Enrichment: Natanz and Fordow
Increasing the concentration of the fissile uranium isotope 235, which is in natural uranium only, from 0.7% to 3 to 5% for power reactors or up to 20% for research reactors.

Reconversion: Natanz
Conversion of enriched UF6 to uranium dioxide (UO2).

Fuel Fabrication: Esfahan
UO2 is sintered to form it into hardened pellets which are sealed inside zirconium alloy tubes for arrangement into fuel assemblies. Light water reactors use enriched uranium and heavy water reactors natural uranium. Research reactor fuel is customarily made of uranium alloys.

Reactor: Light Water Power Reactor at Bushehr, Heavy Water Reactor at Arak, Research Reactors in Teheran and Esfahan
Fuel assemblies are loaded into a reactor for use in the generation of electric power.

Reprocessing: Not in Current Plans
Recovery of the residual unburned uranium and newly produced plutonium in fuel that has been in use for three or four years or so (spent fuel) and separation of the radioactive waste.

39. 'Nuclear Fuel Cycle', *IAEA*, undated, www.iaea.org/OurWork/ST/NE/NEFW/Technical-Areas/NFC/images/nfc-image-big.jpg.

3. Current Status of the Nuclear Programme

Uranium Resources

States utilising or considering adding nuclear power to their energy mix need to have confidence in their ability to obtain nuclear fuel in an assured and predictable manner. Iran, in spite of its large hydrocarbon resources, is no exception to that. Albeit in the history of the nuclear industry, there has never been a disruption of supply that has led to a loss of electricity generation, utilities secure the efficacy of their fuel supply chain by securing uranium, conversion, enrichment, and fuel fabrication services. Like any other chain, it is no stronger than its weakest link. If you are not able to buy enrichment services, you will likely have the same trouble with buying uranium. Similarly, for nuclear fuel, you need – in addition to uranium and enrichment – fuel fabrication technology to be totally independent.

Iran's published energy plans include acquiring a 20,000 MWe nuclear capacity, and construction of four research reactors, which will be, inter alia, according to Iran, designed to produce isotopes for medical purposes. To support this, Iran has been developing supporting infrastructure, which includes two uranium mines (Gachine and Saghand), and a uranium conversion facility in Isfahan, where also additional installations for fuel fabrication are being planned or constructed. The Iranian government plans to develop up to 8 GWe net of installed nuclear capacity by 2025 in order to reduce its reliance on fossil fuels, beginning with the installation of three more units at Bushehr. It has reportedly been in discussions with the Russian Federation to expand co-operation and engage in identifying potential sites for additional reactors.

This ambitious programme will reduce reliance on fossil fuels, but it will need substantial uranium resources to support it. The recently published OECD/IAEA Red Book on global uranium resources and production indicates that Iran has very scarce domestic uranium deposits.[40] According to the Book, which uses data given by the Atomic Energy Organization of Iran (AEOI), the annual uranium needed for the Bushehr 915 MWe is 160 tons. According to the AEOI, Gachine and the other milling facility in Ardakan produce about 70 tons of uranium annually, which is less than half of current Iranian needs. Iran estimates that with the additional nuclear power reactors the need will be for at least 590 and 1,230 tons of uranium annually in 2020 and 2035 respectively. According to this assessment, Iran's total recoverable uranium resources in Ardakan and Gachine are about 1,000 tons.

In other words, the nuclear programme of Iran will depend heavily on uranium imports, a fact that was already recognised in 2003 in the debate in the Iranian Parliament, when several parliamentarians questioned the reasonableness of investing in nuclear power when, in their view then (only Saghand mine was then known) only 15-20% of needed uranium could be covered from domestic resources, and only for one reactor. The price of domestic uranium will be an additional argument in the Majlis with regard to the agreement on the "practical needs" of the nuclear programme to be concluded with the P5+1. According to the Red Book, Iranian uranium will cost US$80-130 per kg of uranium, when the current international spot market in August 2014 had a price tag of US$63 per kg of uranium.[41]

What this means is that in considering Iran's practical needs, the nuclear issue has other facets that in actual fact reduce the scope of what Iran can and should produce in a realistic assessment of a civilian nuclear path forward.

40. Uranium 2014: Resources, Production and Demand, A Joint Report by the OECD Nuclear Energy Agency and the International Atomic Energy Agency, NEA No. 7209, Nuclear Energy Agency, Organization for Economic Co-operation and Development, 2014.

41. Nuclear Intelligence Weekly, Vol VIII, No 35, 29 August 2014.

Uranium Conversion

Total world annual uranium conversion capacity has remained constant in past years at around 76,000 tons of UF6 per year.[42] Commercial scale plants for the conversion of triuranium octaoxide (U3O8) to uranium hexafluoride (UF6) are operating in six countries.[43] Small uranium conversion facilities are in operation in several countries,[44] including the Uranium Conversion Facility (UCF) in Esfahan, Iran. Total current demand for conversion services (assuming an enrichment tails assay[45] of 0.25% uranium-235) is in the range of 60,000–64,000 tons per year.[46] There is additional conversion capacity under construction, inter alia, in France and the US, which means that there is no shortage of uranium conversion services in coming years.

UCF is a conversion facility for the production of both natural UF6 and natural UO2 from uranium ore concentrate (UOC). It is planned that UCF will also produce UF4 from depleted UF6, and uranium metal ingots from natural and depleted UF4. The conversion capacity of the UCF, 200 tons of UF6 annually, is sufficient to cover the reloading needs of one Bushehr reactor.

Since Iran began uranium conversion and fuel fabrication at its declared facilities, it has produced 550 tons of natural UF6 at UCF, of which 163 tons have been transferred to Natanz and Fordow for enrichment.[47]

Enriched UO2 Powder Plant (EUPP) is a facility in Esfahan for the conversion of UF6 enriched up to 5% U-235 into UO2 powder. Iran began commissioning the facility in May 2014 using natural uranium as feed, starting operations in July with feeding UF6 enriched up to 5% U-235. These operations were prompted by the JPOA in which Iran committed by 2014 July to bring the stocks of UF6 to the level of November 2013 inventories by converting the excess material to uranium dioxide (UO2). With this capacity, UCF is able to cover the annual reconversion needs for a reload of a reactor of the size of Bushehr.

Fuel Plate Fabrication Plant (FPFP) in Esfahan is a facility, which manufactures fuel assemblies made of fuel plates for research reactors. This facility has a small process line to convert UF6 enriched up to 20% U-235 into U3O8, which is then used for fuel fabrication.

Uranium Enrichment

Total global enrichment capacity is currently about 65 million separative work units (SWU) per year, compared to a total demand of approximately 49 million SWU per year.[48] Commercial enrichment services are carried out by five companies: China National Nuclear Corporation (CNNC), AREVA (France), ROSATOM (Russian Federation), USEC and URENCO (both USA).

Fuel Enrichment Plant (FEP) and Pilot Fuel Enrichment Plant (PFEP) are located in Natanz. Another enrichment plant, Fordow Fuel Enrichment Plant (FFEP), is near the town of Qom. In addition, Iran has centrifuges R&D facilities in Tehran (Kalaye Electric) and in Esfahan (Farayand Technique), which are not using nuclear material for experiments. Iran also has a large supporting industry to produce components and assemble centrifuges distributed across several locations in Iran.

42. Nuclear Technology Review 2014, IAEA, para. 36, GC(58)/INF/4, 7 July 2014.

43. Canada, China, France, Russian Federation, UK and USA.

44. Argentina, Brazil, Japan and Pakistan.

45. The tails assay, or concentration of uranium-235 in the depleted fraction, indirectly determines the amount of work that needs to be done on a particular quantity of uranium in order to produce a given product assay. An increase in the tails assay associated with a fixed quantity and a fixed product assay of enriched uranium lowers the amount of enrichment needed, but increases natural uranium and conversion requirements, and vice versa. Tail assays can vary widely and will alter the demand for enrichment services.

46. Nuclear Technology Review 2014, IAEA, para. 43, GC(58)/INF/4, 7 July 2014.

47. IAEA, "Implementation of the NPT Safeguards Agreement and Relevant Provisions of Security Council Resolutions in the Islamic Republic of Iran," GOV/2014/43, 5 September 2014.

48. Nuclear Technology Review 2014, IAEA, para. 45, GC(58)/INF/4, 7 July 2014.

Iran is developing several types of gas centrifuges in parallel.

- **IR-1** centrifuge is based on the early Dutch SNOR design acquired by Pakistani scientist Abdul Qadeer Khan, who developed it further and called it "P1." The design was subsequently given to Iran, Libya, and North Korea.
- **IR-2m** is likely to have a carbon fiber with maraging steel bellows. It is based on the Pakistani P2 centrifuge, a German design acquired by A.Q. Khan, which uses a maraging steel rotor.
- **IR-3** centrifuge is one of the prototype centrifuges tested at Iran's Pilot Fuel Enrichment Plant.
- **IR-4** centrifuge is likely an Iranian design based on Pakistan's P2 centrifuge, but believed to use carbon fiber for both the rotor and bellows.
- **IR-5, IR-6, and IR-8** centrifuges are prototypes tested at Iran's Pilot Fuel Enrichment Plant.

(Credit: Siamak Ebrahimi at Tasnim News Agency)

Fig 6. IR-1, IR-2m and IR-4 centrifuges[49]

49. 'Collection of display cutaways of various IR-type nuclear centrifuge units', *Uskowi on Iran*, February 2014.

FEP is a plant for the production of enriched uranium up to 5% U-235, which was first brought into operation in 2007. It has two large underground cascade halls, which can each contain approximately 25,000 centrifuges in 144 cascades.

In August 2014 Iran had installed at the FEP 15420 IR-1 (90 cascades) and 1008 IR-2m (6 cascades) centrifuges. Out of these 9156 IR-1 centrifuges were fed with the natural UF6 gas. In addition, Iran has completed preparatory work for additional 12 IR-2m and 36 IR-1 cascades.

PFEP is a pilot plant LEU production, but is currently used for research and development (R&D). It was first brought into operation in October 2003. It can accommodate six cascades or approximately 1,000 centrifuges.

FFEP is, a centrifuge enrichment plant for the production of UF6 enriched up to 20% U-235 and the production of UF6 enriched up to 5% U-235.31. The facility, which was first brought into operation in 2011, is designed to contain up to 2,976 centrifuges. All of the centrifuges installed are IR-1 machines. As required by the JPOA, cascades were modified to produce only UF6 enriched up to 5% by removing an interconnection between tandem cascades.

Since Iran began enriching uranium at its declared facilities, it has produced 12,772 kg of UF6 enriched up to 5% U-235 at those facilities. As required by the JPOA Iran stopped producing UF6 enriched up to 20% U-235. Until then it had produced 447.8 kg of such nuclear material, all of which has been further processed through down blending to natural uranium or converted into 20% enriched uranium oxide as required by the JPOA.

Fuel Fabrication

The current annual demand for light water reactor (LWR) fuel fabrication services is about 7,000 tons of enriched uranium in fuel assemblies, but is expected to increase to about 8,000 tons uranium per year by 2015.[50] There are now several competing suppliers for most fuel types. Total global fuel fabrication capacity remained at about 13,500 tons uranium per year (enriched uranium in fuel elements and fuel bundles).

There are new constructions underway. A fuel fabrication facility in Kazakhstan is scheduled to be completed in 2014 as a joint venture by AREVA and Kazatomprom.[51] The construction of a WWER-1000 fuel fabrication plant, with a planned capacity of 400 tons uranium per year, has continued near Smoline, Ukraine.[52]

Over the past few years there has been diversification in fuel manufacturing services. Russian company TVEL has produced pilot fuel assemblies that are to be loaded for test operation in Sweden's Ringhals-3 PWR plant in 2014.[53] Westinghouse has manufactured fuel assemblies for Ukrainian reactors on a small scale.

Fuel Manufacturing Plant (FMP) is a facility in Isfahan for the fabrication of nuclear fuel assemblies for power and research reactors.

As a part of the JPOA, Iran has continued its cessation of production of nuclear fuel assemblies using natural UO2 for the IR-40 Reactor.

Fuel Plate Fabrication Plant (FPFP) is a facility in Isfahan, which manufactures fuel assemblies for Tehran Research Reactor (TRR). The fuel plates are made of 20% U-235 U3O8. As of 17

50. Nuclear Technology Review 2014, IAEA, para. 54, GC(58)/INF/4, 7 July 2014.

51. Expected capacity of 1200 t U per year.

52. Nuclear Technology Review 2014, IAEA, para. 57, GC(58)/INF/4, 7 July 2014.

53. Nuclear Technology Review 2014, IAEA, para. 58, GC(58)/INF/4, 7 July 2014.

August 2014, Iran had produced at FPFP one experimental fuel assembly and 27 TRR-type fuel assemblies.

Reactors

Bushehr Nuclear Power Plant (BNPP) is the only nuclear power plant in Iran. German companies started the construction of the plant in 1975, but work stopped in 1979 after the Islamic Revolution. In 1995, Iran signed a contract to finish the plant with the Russian Ministry of Atomic Energy. The 935 MWe light water reactor (LWR), known also with acronym VVER-1000, began producing electricity in September 2011.

Darkhovin is the site of a future Iranian-designed 360 MWe Nuclear Power Plant, where construction was originally planned to start in 2011. The site is located in Ahvaz in southwest Iran, where a French power reactor had been slated to be built until construction was cancelled after the 1979 Islamic Revolution.

IR-40 Reactor is a 40 MW heavy water moderated research reactor under construction in Arak. The reactor is using natural uranium fuel. Spent fuel from such a reactor contains significant quantities of plutonium. This size of reactor is capable of producing weapons-grade plutonium sufficient at least for one nuclear device annually. Iran has stated that the purpose of the reactor is training, research and production of radioisotopes for medical and industrial purposes.

As a part of the JPOA agreement, Iran agreed to suspend installation of the reactor's remaining major key nuclear components.

Heavy Water Production Plant is a facility next to IR-40 reactor for the production of heavy water with a design capacity to produce 16 tons of reactor-grade heavy water per year. To operate IR-40 needs about 90 tons of heavy water.

Reprocessing

Iran is required, pursuant to the relevant resolutions of the Board of Governors and the Security Council, to suspend its reprocessing activities, including R&D. Iran stated in January 2014 that "during the first step time-bound, Iran will not engage in stages of reprocessing activities, or construction of a facility capable of reprocessing". This "voluntary measure" had been extended by Iran in line with the extension of the JPOA.

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