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REPORT

Five Compromises to Avoid in a Comprehensive Agreement with Iran

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A long term, comprehensive solution under the Joint Plan of Action needs to ensure Iran uses nuclear energy for exclusively peaceful purposes. Any such agreement will be complex and require a range of interrelated provisions. We have evaluated five commonly discussed proposals based on a set of criteria, including breakout potential, reversibility, stability, and verifiability and found them flawed. As a result, they should not be part of a long term agreement. They are:

- *(Bad compromise 1) increasing allowed centrifuge numbers significantly while lowering low enriched uranium (LEU) hexafluoride (and oxide) stocks toward zero;*
- *(Bad compromise 2) allowing Iran to maintain in the Arak reactor a core holding significantly more fuel channels than required for fueling the reactor with low enriched uranium fuel;*
- *(Bad compromise 3) agreeing that Iran's centrifuge plants can maintain installed but non-enriching centrifuges designated as in excess under the limits of the deal;*
- *(Bad compromise 4) leaving the resolution of Iran's past and possibly ongoing nuclear weaponization and military fuel cycle efforts until after a deal is concluded and economic and financial sanctions are loosened, if not removed; and*
- *(Bad compromise 5) lack of constraints banning in a verifiable manner future Iranian illicit nuclear procurement efforts*

Since late 2013, we, in consultation with a variety of governmental and outside technical experts, have evaluated various elements of a possible comprehensive solution with Iran that would follow the Joint Plan of Action. In January 2014, ISIS published a model comprehensive solution that contained a range of constraints and conditions.[2] The constraints developed by ISIS aim to establish verifiable, irreversible limits on Iran's ability to produce the nuclear explosive materials highly enriched uranium (HEU) and plutonium and develop and manufacture nuclear weapons. These provisions are summarized in the Appendix to this report and can found in a more detailed form in the original report.

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[2] *Defining Iranian Nuclear Programs in a Comprehensive Solution under the Joint Plan of Action* (Washington, DC: Institute for Science and International Security, January 15, 2014).
http://www.isisnucleariran.org/assets/pdf/Elements_of_a_Comprehensive_Solution_20Jan2014_1.pdf

We believe these provisions and the associated verification measures would protect the national security interests of the United States and its allies. The resulting limited nuclear programs that would remain in Iran and expected extensive verification measures would eliminate the risk of Iran breaking out to nuclear weapons at declared or covert nuclear sites without that effort being detected in a timely manner. There would be adequate time for U.S. and international responses that would prevent Iran from succeeding in that effort.

A comprehensive solution such as the one proposed by ISIS necessarily involves many interrelated elements. Models of such agreements can differ and we recognize that elements of the ISIS model can change without changing an agreement's overall effectiveness. Undergirding the ISIS model are arms control and non-proliferation principles which we believe are fundamental to any model. In deriving constraints, ISIS applied the following guiding principles:

- **Adequate breakout times**[3] of at least 6-12 months based on a rigorous assessment of Iran's centrifuge cascade configurations. Six months is considered a minimum breakout time to put together an effective international response in a post-agreement environment.[4] Some analyses have shown that even six months may not be sufficient to mount an effective response. As a result, a six month breakout must be viewed as a minimum breakout period. A longer one is preferred. In terms of centrifuge numbers, a 6-12 month breakout time translates to 2,000-4,000 IR-1 centrifuges or an equivalent number of advanced centrifuges.[5]
- **Irreversibility**, where irreversibility is used in the traditional arms control context, accepting that perfect irreversibility is not possible but in practice recognizes that

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[3] Breakout times at enrichment plants are defined as the length of time Iran would need to produce in such plants enough weapon-grade uranium for a nuclear weapon. We use the standard value of 25 kilograms of weapon-grade uranium as enough for a nuclear weapon. ISIS determines breakout times through a rigorous assessment of centrifuge cascade performance and does not rely on ideal cascade calculations, which are inaccurate in the case of Iranian centrifuge plants and in general produce significantly shorter breakout times. For background on ISIS breakout estimates, the reader is referred to the ISIS web site at www.isis-online.org

[4] Shorter breakout times in theory could be tolerated if the parties to an agreement remained prepared to act militarily to prevent a breakout in Iran on short notice. Although military options are currently threatened as part of U.S. policy to prevent Iran from gaining nuclear weapons, such a policy is not realistic or preferable as a long-term strategy. Moreover, depending on unilateral military options to deter breakout or prevent it from succeeding would not bode well for the acceptability or workability of a comprehensive solution, let alone be politically acceptable in the United States and much of the world. Thus, there is a requirement for meaningful limits on Iran's nuclear capabilities that provide timely warning of any move by Iran to build nuclear weapons and greater assurances that Iran's nuclear program will be exclusively peaceful. Achieving this goal requires breakout times that exceed six months.

[5] Because Iran may seek to replace the IR-1 centrifuges with more capable ones, a more general enrichment cap is derived from the cap on IR-1 centrifuges developed above and is approximately 3,600 swu/year. This value serves as a general enrichment cap regardless of the actual enrichment capacity of any centrifuge that would replace the IR-1 centrifuge in the future. If Iran deployed IR-2m centrifuges, for example, the parties would need to agree upon an average centrifuge enrichment value before deriving the number of IR-2m centrifuges needed to produce 3,600 swu/yr. For example, if an IR-2m centrifuge has an average enrichment output of 4 swu per year, then the cap would be 900 IR-2m centrifuges. If Iran deploys any other enrichment technology, such as laser enrichment, it and any centrifuge plant would need to have a total enrichment output at this cap or below.

reverting back to the previous, unconstrained situation should take a long time and be defined as taking on order of years and not months.

- **Stability**, defined as provisions that create a situation less likely to lead to on-going accusations of violations or that would not require an inordinate number of actions to maintain compliance, particularly if there is an incentive or little risk to violating that provision.
- **Sufficient, legally binding transparency** to allow effective verification by the IAEA that provides early warning of breakout, the determination of the correctness and completeness of Iran's declarations, and assurance about the absence of undeclared nuclear activities or facilities. While voluntary offers of transparency are welcome, experience has shown that transparency should be mandated in an agreement.
- **An understanding of how Iran acquires the means to make sensitive nuclear facilities and operate them**. This principle is important in constructing an adequate verification regime able to detect clandestine nuclear facilities and activities. It also requires a focus on Iran's persistent efforts to procure key goods illegally for its nuclear programs. These efforts violate not just sanctions but also export control laws which will continue under any long term agreement with Iran.

In addition to guiding the development of provisions in the ISIS model comprehensive agreement, these principles also permit a method to determine why certain provisions are less desirable or even represent bad compromises that should be set aside. We applied these criteria to a range of provisions, several developed in ISIS-sponsored technical workshops, and others discussed publicly. Some of the ISIS provisions were developed at the request of government officials struggling to find solutions to what constitutes an acceptable deal. Several compromises are quite useful; others are not wise to pursue, including some weighed by experts in these workshops and consultations. This report has focused on a subset of proposals which should be abandoned due to their flawed nature.

Bad Compromise 1: Increasing centrifuge numbers above 2,000-4,000 IR-1 centrifuges while lowering low enriched uranium (LEU) hexafluoride (and oxide) stocks toward zero

Bad Compromise 2: Deciding that Iran can maintain significantly more fuel channels in the Arak reactor core than it requires for fueling the reactor with low enriched uranium fuel

Bad Compromise 3: Agreeing that Iran can maintain at an enrichment plant installed but non-enriching centrifuges designated as in excess under the limits of the deal

Bad Compromise 4: Leaving the resolution of Iran's past and possibly ongoing nuclear weaponization and military fuel cycle efforts until after a deal is concluded and economic and financial sanctions are loosened, if not removed

Bad Compromise 5: Lack of constraints banning in a verifiable manner future Iranian illicit nuclear procurement efforts

Certainly, a key recommendation is that the P5+1 negotiators avoid integrating these unacceptable compromises into any deal's provisions. If accepted, these compromises would create a final agreement that would be unstable, overly reversible, and likely unverifiable.

The rejection of these provisions, several of which are favored by Iran, is bound to cause protests. But it should be remembered that Iran is the party that has for many years violated its non-proliferation commitments. Thus Iran is the party that will need to make significant concessions if it wants a deal that includes sanctions relief.

Bad Compromise 1: Increasing centrifuge numbers above 2,000-4,000 IR-1 centrifuges while lowering low enriched uranium (LEU) hexafluoride (and oxide) stocks toward zero.

In addition to lowering centrifuge numbers significantly, the agreement should aim to lower Iran's stocks of LEU and natural uranium. One modification in the ISIS model concerns 3.5 percent LEU stocks, which should be lowered further down to a 1-5 tonnes (see appendix). Lowering both quantities would make it more difficult for Iran to break out and would create a more irreversible, stable agreement. However, lowering stocks without lowering centrifuge numbers is not a workable proposition.

Treating these two, reinforcing steps instead as a zero-sum game leads to the first bad idea. In this scheme, the number of centrifuges would be raised substantially, to 8,000 or more IR-1 centrifuges or equivalent number of advanced ones, while lowering the stocks of 3.5 percent LEU toward zero. In one version of this scheme, only the amount of 3.5 percent LEU hexafluoride would be reduced toward zero via conversion into LEU oxide. Once in oxide form, it would somehow be considered no longer usable in a breakout. But this is wrong. Both chemical forms of LEU have to be considered since Iran can in a matter of months reconvert LEU oxide into hexafluoride form and then feed that material into centrifuges, significantly reducing total breakout time.[6] Iran does not have a way to use large quantities of 3.5 percent LEU in a reactor, so irradiation cannot be counted on to render these oxide stocks unusable. This means that proposals that merely lower the quantity of LEU hexafluoride by converting it into oxide form or fresh fuel is an even more unstable, reversible idea than variants that lower total LEU stocks to zero.

Some background is helpful. This proposal is fundamentally based on Iran not possessing enough 3.5 percent LEU to further enrich and obtain enough weapon-grade uranium (WGU) for

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[6] Iran already has the technology and skills to convert uranium dioxide (UO_2) back to uranium hexafluoride (UF_6). Iran built a lab scale plant to do this in 1990's and has subsequently completed the Uranium Conversion Facility in Esfahan. In addition, both the less than 5 % $LEUO_2$ and the near 20 % LEU_3O_8 are fairly pure, meaning that Iran can more easily reconvert the oxide back to hexafluoride form. For example, it could use direct fluorination process without having to first apply solvent extraction.

a nuclear weapon, taken here as 25 kilograms. If Iran had less than 1,000 kilograms of 3.5 percent LEU hexafluoride, it would not have enough to produce 25 kilograms of WGU.[7] Its breakout time would increase because it would be required to also feed natural uranium into the centrifuges. It could not use the three-step process, where WGU is produced in three steps, with the greatest number of centrifuges taking 3.5 percent to 20 percent LEU, a smaller number enriching from 20 to 60 percent, and a smaller number still going from 60 to 90 percent, or WGU. Instead, Iran would need to add a fourth step at the "bottom" enriching from natural uranium to 3.5 percent LEU. This step would require a large number of centrifuges and thus fewer would be available for the other steps, lengthening breakout times.

Figure 1 shows mean breakout times for a four-step process, where the amount of LEU varies from 0-1000 kilograms of 3.5 percent enriched uranium hexafluoride and each graph represents a fixed number of IR-1 centrifuges, from 4,000 to 18,000. In this case, it is assumed that Iran would have no access to near 20 percent LEU hexafluoride, a dubious assumption (see below). In the figure, a six month breakout time is represented by the black horizontal line on the graph. Several cases are noteworthy. For less than 6,000 IR-1 centrifuges, all of the breakout times exceed six months. For 10,000 IR-1 centrifuges, the breakout time is six months for stocks of 1,000 kilograms of 3.5 percent LEU hexafluoride and exceeds six months for lesser amounts of LEU. For 14,000 centrifuges, when the stock is below about 500 kilograms of 3.5 percent enriched uranium hexafluoride, the breakout time is six months or more. For 18,000 centrifuges, a six month breakout time only occurs for an inventory of zero kilograms of 3.5 percent enriched uranium, a physical impossibility. That number of centrifuges would produce several hundred kilograms of 3.5 percent LEU hexafluoride every month. Much of this material would be in the product tanks hooked to the cascades and thus readily usable. So, cases of no LEU are not achievable.

In fact, a major weakness in this suggested provision is that the very product produced by the centrifuges, namely 3.5 percent LEU, would need to be regularly eliminated through some process. Obtaining this level of compliance would be challenging. Even if the LEU were to be shipped overseas, Iran could hold back sending it abroad, building up a large stock. Similarly, if it were converted into an oxide form, Iran could delay doing so, feigning problems in the conversion plant or delays in transporting it to the plant for conversion. Moreover, conversion to oxide as mentioned above can be rapidly reversed, allowing a three-step process and significantly faster breakout.

[7] In general terms, a stock of about 1,200 to 1,500 kilograms of 3.5 percent LEU hexafluoride is enough to allow for a three-step process. In this report, we will use the upper bound of this range, or 1,500 kilograms, as a benchmark for enough 3.5% LEU to produce 25 kilograms of weapon-grade uranium in a three step process. If a four step process is used instead with an inventory of 1,500 kilograms, the breakout time will be about almost 40 percent greater than in the case of a three-step process. The increase in time is mainly a result of the assignment of a significant number of centrifuges to the step going from natural uranium to 3.5 percent LEU, leaving fewer centrifuges enriching in the steps from 20 to 90 percent. If the stock is 2,000 kilograms of 3.5 percent LEU hexafluoride, the breakout time in the case of a four-step process will be almost double that of a three step process. Although no one would likely use a four step process in this case, these estimates illustrate that using a four-step process lengthens breakout time significantly.

In the unlikely case of Iran not mustering any near 20 percent LEU hexafluoride, a plant with 10,000 IR-1 centrifuges would correspond to a six-month breakout limit if the stock did not exceed 1,000 kilograms of 3.5 percent LEU hexafluoride. In two months, however, another five hundred kilograms could be produced in this number of centrifuges, with the total 3.5 percent LEU stock reaching 1,500 kilograms and allowing a three step breakout, which could occur in a matter of a few months. Thus, in practice, LEU stocks would need to be maintained at levels far below 1,000 kilograms, even in the case of 10,000 IR-1 centrifuges. And keeping the stocks below this limit is not very likely to succeed. If Iran kept more than 10,000 IR-1 centrifuges, the situation is more untenable.

The above discussion assumes that Iran could not use near 20 percent LEU hexafluoride. Why is this, in fact unlikely to be the case? Iran has stockpiled near 20 percent LEU oxide to fuel the Tehran Research Reactor, and by using this stock, it could reduce breakout times considerably after reconverting the near 20 percent LEU oxide into hexafluoride form. At the end of the interim period (July 20, 2014), Iran is expected to have a total stock of at least 135-170 kg of near 20 percent LEU oxide that will be relatively easy to convert back to the hexafluoride form for further enrichment.[8] This amount, if reconverted, would result in about 200-250 kg of near 20 percent hexafluoride, nearly the amount, if further enriched, to yield enough weapon-grade uranium for a nuclear weapon. The comprehensive agreement is expected to reduce the size of the near 20 percent LEU stock but not eliminate it, if the agreement allows Iran to produce Tehran Research Reactor (TRR) fuel domestically. In the future, Iran could start to reconvert this material to hexafluoride form in a matter of months and dramatically speed up breakout.[9] Figure 2 shows the impact of only 50 kilograms of near 20 percent LEU hexafluoride on mean breakout times, where again a four-step process is used. With just 50 kilograms of near 20 percent LEU hexafluoride, a stock of 500 kilograms of 3.5 percent LEU hexafluoride, and 10,000 IR-1 centrifuges, breakout time would be six months. For comparison, in the case of no near 20 percent LEU discussed above, 10,000 IR-1 centrifuges could achieve a six-month breakout only with a stock of 1,000 kilograms of 3.5 percent LEU hexafluoride. So, 50 kilograms of near 20 percent LEU hexafluoride is equivalent to roughly 500 kilograms of 3.5 percent LEU hexafluoride. If a stock of 50 kilograms of near 20 percent LEU hexafluoride is used in conjunction with a stock of 1,000 kilograms of 3.5 percent LEU hexafluoride, Iran would have enough LEU hexafluoride to use a three-step process to break out and achieve breakout times of a few months.

So, in the realistic case whereby Iran accumulates only 50 kilograms of near 20 percent LEU hexafluoride, the maximum cap on the number of centrifuges would be 10,000 IR-1 centrifuges and the stock of 3.5 percent LEU could not exceed 500 kilograms. While in theory this limit could be maintained, in practice that is highly unlikely. Each month, such a plant would produce almost 250 kilograms of 3.5 percent LEU hexafluoride. In two months, Iran could

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[8] David Albright, Patrick Migliorini, Christina Walrond, and Houston Wood, "Update on Iran's Total Near 20 Percent Enriched Uranium Stock: Nearly Enough for a Bomb, if Further Enriched," *ISIS Report*, March 11, 2014. http://isis-online.org/uploads/isis-reports/documents/twenty_percent_stock_march_11_2014-final.pdf

[9] Iran could reconvert to hexafluoride form either before starting to breakout or afterwards. The total breakout time is similar in both cases.

exceed the cap by 500 kilograms, reaching a total of 1,000 kilograms of 3.5 percent LEU hexafluoride, or enough if used in combination with the near 20 percent LEU hexafluoride stock to reduce breakout times to about four months, all the while claiming that some reasonable problems prevent it from removing the excess material.

In the case that the limits are taken at near zero kilograms of 3.5 percent LEU, say 100 kilograms of such LEU, that agreement would be very difficult, if not impossible, to maintain. Maintaining this level would require a major effort that would run contrary to the manner in which centrifuge and conversion programs are operated. Thus, positing a near zero limit would lead to an agreement that Iran would likely continually violate, if only accidentally, potentially undermining the credibility of the entire agreement and making enforcement of violations that much harder.

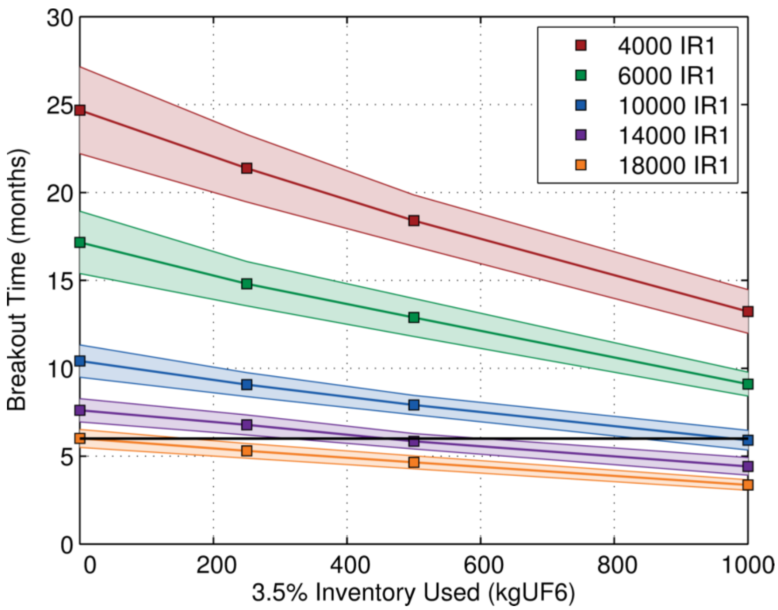
On balance, while this proposal is superficially attractive, it is unstable and reversible, requiring Iran to constantly do something it may simply choose to stop doing one day. It could move to hide any violation in the cap by claiming logistical or operational difficulties, many of which would be expected to occur in a program like Iran's. Any reversal could be sudden and difficult to respond to. Overall, these types of proposals, if accepted, would lead to a bad deal.

Figure 1: Four Step Enrichment Predictions with no near 20 Percent LEU

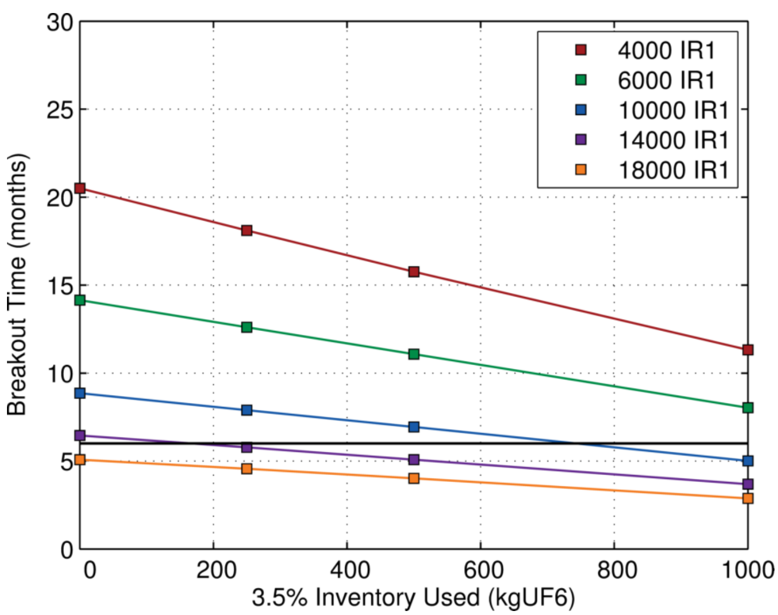
Breakout Time Calculation (includes 2 week setup time)

4000, 6000, 10000, 14000, 18000 IR-1 Centrifuges

Range of 3.5% Inventory Used, 0-1000 kg UF_6



Mean (with range) breakout time versus 3.5% inventory used



Minimum breakout time versus 3.5% inventory used.

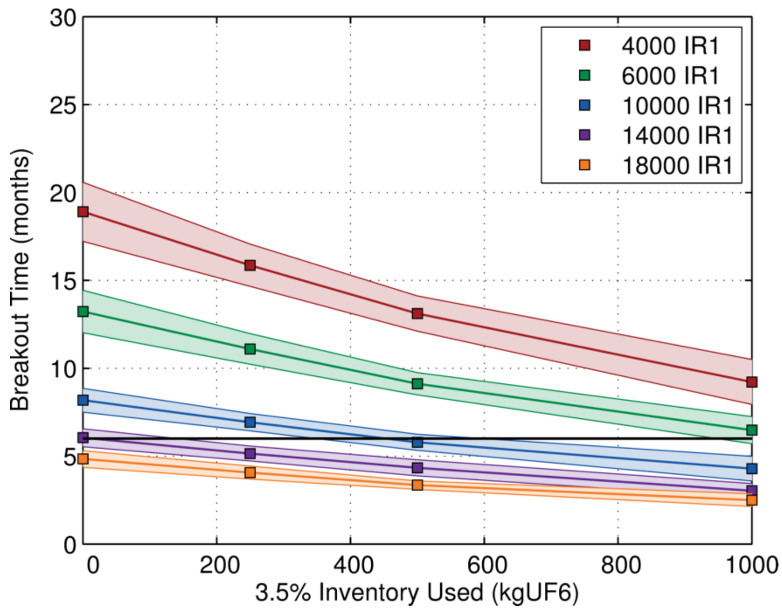
Note: The results are calculated as breakout times for various numbers of centrifuges and amounts of 3.5% inventory used, with multiple scenarios for each number of centrifuges matched with a specific 3.5% inventory. Two sets of breakout times are reported in the figures mean with range and minimum value of all scenarios. The results in the text use the mean values. The minimum values are viewed as worst case estimates which may be unlikely to be achieved in practice.

Figure 2: Four Step Enrichment Estimate with 50 kg near 20 percent $LEUF_6$ Used

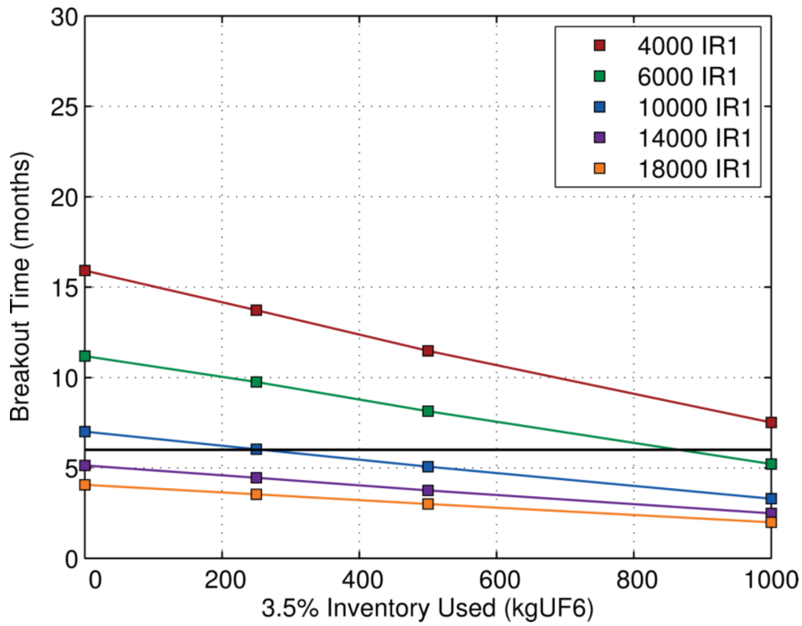
Breakout Time Calculation (includes 2 week setup time)

4000, 6000, 10000, 14000, 18000 IR-1 Centrifuges

Range of 3.5% Inventory Used: 0-1000 kg $LEUF_6$



Mean (with range) breakout time versus 3.5% inventory used



Minimum breakout time versus 3.5% inventory used

Note: The results are calculated as breakout times for various numbers of centrifuges and amounts of 3.5% inventory used, with multiple scenarios for each number of centrifuges matched with a specific 3.5% inventory. Two sets of breakout times are reported in the figures: mean with range and minimum value of all scenarios. The results in the text use the mean values. The minimum values are viewed as worst case estimates which may be unlikely to be achieved in practice.

Bad Compromise 2: Deciding that Iran can maintain significantly more fuel channels in the Arak reactor core than it requires for fueling the reactor with low enriched uranium fuel

Iran appears to accept that it must limit plutonium production in the heavy water Arak nuclear reactor (IR-40), which is almost 90 percent complete and under a construction moratorium because of the interim nuclear deal.[10] As presently designed, the reactor can be used relatively easily to make weapon-grade plutonium, at a production rate of up to about nine kilograms a year. This plutonium could later be separated and used in nuclear weapons.

A few strategies for lowering plutonium production have been discussed publicly; one recent recommendation published in *Arms Control Today* by Princeton University scientists suggests using five percent enriched uranium fuel instead of natural uranium fuel and lowering the power of the reactor by more than half, from 40 megawatts-thermal (MWth) to 10-20 MWth.[11] This proposal would involve placing LEU fuel in a small fraction of the fuel channels in a large vessel – often called a "calandria"-- through which the heavy water moderator and coolant flows. The Arak calandria has about 175 fuel and control rod channels (see figure 3). The LEU would be inserted into the middle section of the calandria with the majority of channels left empty (see figure 4). The authors did not discuss two problems in their approach, namely whether the calandria would be replaced with one sized for LEU fuel and the heat exchangers would be downsized appropriately to those needed for a 10-20 MWth reactor.

Although the outcomes of reduced power and enriched uranium fuel are preferred, leaving Iran with an unmodified Arak calandria and its original heat exchangers constitutes an unacceptable proposal. If the core and heat exchangers were left intact, Iran could in a straightforward manner switch back to a natural uranium core and 40 MWth of power, undoing this limitation on plutonium production. This reconversion could occur in the open and under IAEA safeguards where Iran creates some pretext, perhaps even claiming the reactor's configuration is not safe after all. There are undoubtedly safety questions about this type of conversion. In terms of the natural uranium fuel, Iran has already made significant progress on preparing a core load of natural uranium fuel, which could be finished, or the experience used to fabricate another one. Once switched back, Iran could run the reactor under safeguards to produce plutonium, even weapon-grade plutonium. Since the reactor would be fully operational, its destruction via military means would be dangerous and highly risky, and on balance unlikely to occur. Then, at the time of its choosing, Iran could breakout, having only to separate the plutonium from the spent fuel, which could be done utilizing a covert, low technology reprocessing plant in a matter of a few months. The designs for this type of plant are unclassified and readily available and such a plant would be very difficult for the IAEA (or intelligence agencies) to detect either during its relatively short construction or subsequent operation.

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[10] Interview with Ali Akbar Salehi: Arak Heavy Water Reactor is for Peaceful Research," Iran Press TV, February 5, 2014, http://www.presstv.ir/detail/2014/02/05/349340/false-allegations-wont-stop-arak-reactor/

[11] Ali Ahmad, Frank von Hippel, Alexander Glaser, and Zia Mian, "A Win-Win Solution for Iran's Arak Reactor," *Arms Control Today*, April 2014. http://www.armscontrol.org/act/2014_04/A-Win-Win-Solution-for-Irans-Arak-Reactor

At a minimum, Iran should remove the existing calandria and replace it with one sized appropriately for a core of the agreed upon number of LEU fuel assemblies. The existing one should be rendered unusable or removed from Iran.

Despite the merits of modifying the Arak reactor, a more effective compromise remains upgrading the Arak reactor to a modern light water research reactor (LWR) which can be designed to be far more capable of making medical isotopes than the current Arak reactor design. It can also be designed to make plutonium production in targets much more difficult to accomplish than the Arak reactor or older style research reactors.

A proposal to do so involves ensuring that the LWR is built irreversibly with a power less than or equal to 10 MWth. This would require remanufacturing of the Arak reactor and changes to the heat exchangers and cooling system. Under this proposal, there is no need to produce heavy water, and the current stocks could be sold on the world market. Production of natural uranium oxide powder, fuel pellets, rods, and assemblies for the Arak IR-40 would be halted. Moreover, the associated process lines would also need to be shut-down, including the production of specifically IR-40 relevant materials such as zirconium tubes. In return, the P5+1 could assist Iran in producing fuel for the LWR. Iran could produce the necessary LEU in its enrichment program.

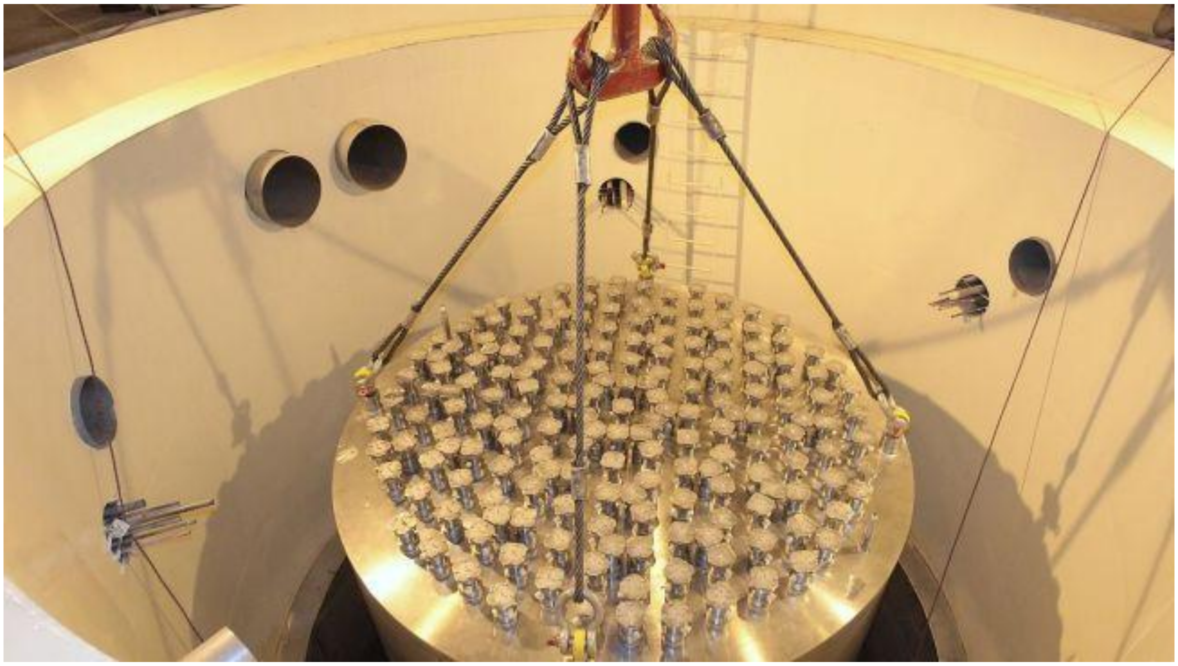

Figure 3: Arak reactor calandria, with about 187 fuel assembly, control rod, and instrumentation channels

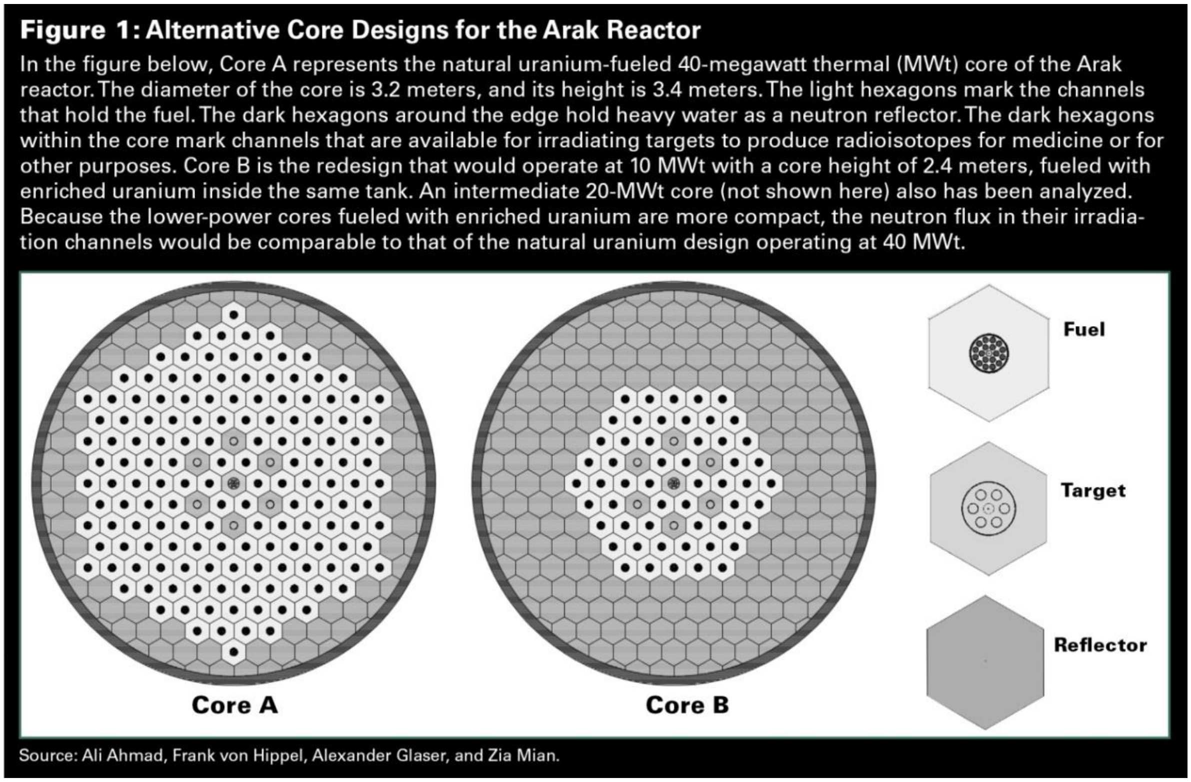

Figure 4: Schematic of Arak Core that illustrates that a significant number of fuel channels would remain empty after conversion to enriched uranium fuel.

Source of figure: Ali Ahmad, Frank von Hippel, Alexander Glaser, and Zia Mian, "A Win-Win Solution for Iran's Arak Reactor," *Arms Control Today*, April 2014. http://www.armscontrol.org/act/2014_04/A-Win-Win-Solution-for-Irans-Arak-Reactor

Bad Compromise 3: Agreeing that Iran can maintain at an enrichment plant installed but non-enriching centrifuges designated as in excess under the limits of the deal

Iran is expected to accept a limit on the number of centrifuges that would enrich uranium in a comprehensive deal. This limit is expected to be smaller than the number of currently installed centrifuges, which is over 18,000 IR-1 centrifuges and about 1,000 IR-2m centrifuges. To allow for an adequate international response in case Iran reneges on the deal, the number of IR-1 centrifuges, or the equivalent number of IR-2m centrifuges, will need to be far fewer than the number installed today. The final number needs to be in the range of 2,000-4,000 IR-1 centrifuges or an equivalent number of advanced centrifuges.[12]

The extra centrifuges in excess of this limit should be removed from the centrifuge plants. If they are not removed Iran could quickly reconstitute its larger enrichment program, and thereby a sizeable breakout capability, if it decided to renege on the deal. Thus, any proposal to keep excess centrifuges installed should be rejected.

Some analysts, including those at ISIS, have discussed imposing essentially what have been called in the North Korean context "disablement" steps, which would delay the restart of installed centrifuges. However, ISIS's attempts to define disablement steps that leave the centrifuges and cascade equipment in place appear to be reversible in two to three months of diligent work.[13] This length of time remains uncertain and it could be shorter. There is no practical experience in disabling centrifuge plants; North Korea's centrifuge program was not subject to disablement. It needs to be pointed out that U.S. policymakers had a tendency to exaggerate the difficulty of undoing North Korean disablement steps imposed at the Yongbyon nuclear center on plutonium production related facilities. In fact, North Korea was able to reverse many of these steps faster than expected or within the technically predicted timeframes. Thus, disablement steps are highly reversible and in fact could be reversed faster than expected.

A sounder strategy involves including disablement steps as a temporary measure until the excess centrifuges are shut down and removed from the Natanz and Fordow enrichment plants. The shutdown of the centrifuges would need to be done with care. URENCO experts should be consulted about the best procedures of shutting them down. Iran's experience in 2003 shutting down a cascade of IR-1 centrifuges left about a third broken. But this was early in the Iranian program, at a time when it used many unwise methods of handling and assembling centrifuges, such as handling rotors with bare hands which caused excessive corrosion, and improperly inserting rotor assemblies into the rotor housings, potentially causing damage to the bottom

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[12] *Defining Iranian Nuclear Programs in a Comprehensive Solution under the Joint Plan of Action*, op. cit.

[13] One disablement proposal investigated by ISIS that should require at least a few months to reverse is the following: (1) Shut down the centrifuges; (2) Remove all control panels, power supplies, frequency converters, wiring, and electronics associated with the operation of the centrifuge cascades and feed and withdrawal areas; and (3) Send the removed equipment to monitored storage at a site away from centrifuge facilities. The cascades could remain under vacuum, although the rotors would not be spinning and all the uranium hexafluoride would be pumped out. This step would reduce corrosion of centrifuge components and other problems which can be caused by air reaching the centrifuges.

bearings. With care and perhaps some guidance, Iran can shut down the IR-1 centrifuges with far less breakage.

An agreed upon fraction of centrifuges and associated cascade piping and equipment should be kept available under monitored storage away from the centrifuge plants as spares to replace broken centrifuges and equipment. This number would be derived from the current rate of breakage which Iran would need to document with the aid of the IAEA. The May 23, 2014 IAEA safeguards report on Iran documents an effort by the IAEA that would help establish just such a number in a reliable manner. Iran provided the IAEA with "an inventory of centrifuge rotor assemblies that will be used to replace those centrifuges that fail," and the IAEA confirmed that centrifuge rotor manufacturing and assembly are consistent with Iran's replacement programme for damaged centrifuges."[14]

The rest of the centrifuges and associated equipment should be thoroughly dismantled and stored or destroyed. The soundest proposal is to store excess centrifuge components and cascade equipment, or an important subset of them, overseas.

Failing that, monitored storage could occur in Iran, but this approach creates several potentially intractable problems, both involving reversibility and instability. The first is that Iran could at some point break the seals at the storage site and truck the centrifuges to a secret site for use in a covert centrifuge plant. It could also re-establish a subset of the centrifuge cascades in a declared plant. The former is certainly the more serious problem but the latter may be a step Iran could take if it grows dissatisfied with the agreement but does not want to fundamentally violate its core conditions and risk a harsh international reaction, including possibly military strikes. The latter would be a serious violation but the response would likely be milder since no breakout would be perceived.

[14] IAEA Director General, *Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions in the Islamic Republic of Iran*, GOV/2014/28, May 23, 2014. http://isis-online.org/uploads/isis-reports/documents/iaea-iranreport-230514.pdf

Bad Compromise 4: Leaving the resolution of Iran's past and possibly ongoing nuclear weaponization and military fuel cycle efforts until after a deal is concluded and economic and financial sanctions are loosened, if not removed

On April 21, 2014 the spokesman of Iran's Atomic Energy Organization told the media that Iran was compiling a complete account of all its nuclear activities and would finish the report in eight months.[15] The spokesman failed to mention, however, whether such a document would address the most contentious issues, namely whether Iran has worked on nuclear weapons. Iran has so far provided little clarity on this issue in nuclear negotiations. The May 23, 2014 IAEA safeguards report, while reporting that Iran has been more willing to discuss aspects of this issue under the November 2013 Framework of Cooperation, implies that the issue remains unresolved and that in fact little progress has been achieved.[16] Overall, measures implemented through the IAEA's Framework of Cooperation and the Joint Plan of Action have only marginally contributed to additional understanding of Iran's alleged past and possibly on-going military nuclear programs.

Supreme Leader Ali Khamenei often declares that nuclear weapons violate Islamic strictures. His denials are not credible. The United States, its main European allies, and most importantly the IAEA itself, assess that Iran had a sizable nuclear weapons program into 2003. The U.S. intelligence community in a 2007 National Intelligence Estimate (NIE) agreed: "We assess with high confidence that until fall 2003, Iranian military entities were working under government direction to develop nuclear weapons." The Europeans and the IAEA have made clear, the United States less so, that Iran's nuclear weapons development may have continued after 2003, albeit in a less structured manner. In its November 2011 safeguards report, the IAEA provided evidence of Iran's pre- and post-2003 nuclear weaponization efforts. The IAEA found, "There are also indications that some activities relevant to the development of a nuclear explosive device continued after 2003, and that some may still be ongoing." Thus, there is widespread evidence and agreement that Iran has worked on developing nuclear weapons. Some of those activities may have continued to today.

Addressing the IAEA's concerns about the military dimensions of Iran's nuclear programs is fundamental to any long-term agreement. Although much of the debate about an agreement with Iran rightly focuses on Tehran's uranium enrichment and plutonium production capabilities, an agreement that side steps the military issues would risk being unverifiable. Moreover, the world would not be so concerned if Iran had never conducted weaponization activities aimed at building a nuclear weapon. After all, Japan has enrichment activities but this

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[15] "Iran Says Drafting Complete Account of Past Nuclear Activities," Reuters, April 21, 2014.

[16] David Albright, Paulina Izewicz, Andrea Stricker, and Serena Kelleher-Vergantini, *ISIS Analysis of IAEA Iran Safeguards Report*, May 23, 2014. http://www.isis-online.org/uploads/isis-reports/documents/ISIS_Analysis_IAEA_Safeguards_Report_23May2014-finaldoc.pdf and *Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions in the Islamic Republic of Iran*, May 23, 2014, op. cit.

program is not regarded with suspicion. Trust in Iran's intentions, resting on solid verification procedures, is critical to a serious agreement.[17]

A prerequisite for any comprehensive agreement is for the IAEA to know when Iran sought nuclear weapons, how far it got, what types it sought to develop, and how and where it did this work. Was this weapons capability just put on the shelf, waiting to be quickly restarted? The IAEA needs a good baseline of Iran's military nuclear activities, including the manufacturing of equipment for the program and any weaponization related studies, equipment, and locations. The IAEA needs this information to design a verification regime. Moreover, to develop confidence in the absence of these activities—a central mission, the IAEA will need to periodically inspect these sites and interview key individuals for years to come. Without information about past military nuclear work, it cannot know where to go and who to speak to.

The situation today, unless rectified, does not allow for the creation of an adequate verification regime. Moreover, the current situation risks the creation of dangerous precedents for any verification regime that would make it impossible for the IAEA to determine with confidence that nuclear weapons activities are not on-going. Adding verification conditions to any deal is unlikely to help if the fundamental problem is the lack of Iranian cooperation. The IAEA already has the legal right to pursue these questions under the comprehensive safeguards agreement with Iran.

Despite the IAEA's rights, Iran has regularly denied the IAEA access to military sites, such as a site at the Parchin complex, a site where high-explosive experiments linked to nuclear triggers may have occurred. Iran has reconstructed much of this site at Parchin, making IAEA verification efforts all but impossible. Tehran has undertaken at this site what looks to most observers as a blatant effort to defeat future IAEA verification. However, Parchin is but one of many sites the IAEA wants to inspect as part of its efforts to understand the military dimensions of Iran's nuclear programs. A full Iranian declaration may reveal even more sites of concern.

Iran continues to say no to IAEA requests to interview key individuals, such as Mohsen Fakrizadeh, the suspected military head of the nuclear-weapons program in the early 2000s and perhaps today, and Sayyed Abbas Shahmoradi-Zavareh, former head of the Physics Research Center, alleged to be the central location in the 1990s of Iran's militarized nuclear research. The IAEA interviewed Shahmoradi years ago about a limited number of his suspicious procurement activities conducted through Sharif University of Technology. The IAEA was not fully satisfied with his answers and its dissatisfaction increased once he refused to discuss his activities for the Physics Research Center. Since the initial interviews, the IAEA has obtained far more information about Shahmoradi and the Physics Research Center's procurement efforts. The need to interview both individuals, as well as others, remains.

If Iran is able to successfully evade addressing the IAEA's concerns now, when biting sanctions are in place, why would it address them later when these sanctions are lifted? Iran's lack of

[17] See David Albright and Bruno Tertrais, "Making Iran Come Clean About its Nukes," *The Wall Street Journal*, May 14, 2014. http://online.wsj.com/news/articles/SB10001424052702304081804579559630836775474

clarity on alleged nuclear weaponization and its noncooperation with the IAEA, if accepted as part of a nuclear agreement, would create a large vulnerability in any future verification regime. How large? Iran would have clear precedents to deny inspectors access to key facilities and individuals. There would be essentially no-go zones across the country for inspectors. Tehran could declare a suspect site a military base and thus off limits. And what better place to conduct clandestine, prohibited activities, such as uranium enrichment and weaponization?

Iran would have also defeated a central tenet of IAEA inspections—the need to determine both the correctness and completeness of a state's nuclear declaration. The history of Iran's previous military nuclear efforts may never come to light and the international community would lack confidence that these capabilities would not emerge in the future. Moreover, Iran's ratification of the Additional Protocol or acceptance of additional verification conditions, while making the IAEA's verification task easier in several important ways, would not solve the basic problem posed by Iran's lack of cooperation on key, legitimate IAEA concerns. Other countries contemplating the clandestine development of nuclear weapons will certainly watch Tehran closely.

Clearly, there is little time for Iran to address all the IAEA's outstanding concerns prior to the July 20 initial deadline. However, Iran can choose to admit to having had a nuclear weapons program and pledge full cooperation with the IAEA. If no such admission and commitment is forthcoming by July 20, negotiations should continue although without further sanctions relief until Iran addresses the IAEA's concerns.

Bad Compromise 5: Lack of constraints banning in a verifiable manner future Iranian illicit nuclear procurement efforts

Iran has resisted efforts to curtail its illicit nuclear procurement activities, which it conducts to obtain goods for its nuclear facilities and programs. Export controls and certain sanctions on nuclear and nuclear-related goods will continue after the signing of a comprehensive deal. If Iran's illicit activities continue after the signing of an agreement, there will be persistent questions about whether it is seeking the wherewithal to build clandestine nuclear sites.

To start, Iran must commit in the agreement not to conduct illicit nuclear trade, defined broadly as trade that violates suppliers' national and regional export controls and sanctions laws and regulations. Iran should commit not to procure goods for its nuclear programs abroad in a manner that is considered illicit ("illicit nuclear trafficking or trade"). Such trafficking is illicit if such trade is not authorized:

- by the state in which goods originate;
- by the United Nations Security Council or regional authorities, such as the European Union
- by the states through which the goods transit; or
- for import into the buying state or for use in an Iranian nuclear program

The P5+1 must include in the agreement a provision that for the duration of a comprehensive agreement nations maintain some sanctions or limitations on the supply of sensitive nuclear and nuclear-related exports to Iran. This list of goods would be expected to contain additional goods not found on dual-use lists maintained under export control regimes but critical to Iran's nuclear programs.

An agreement will also need to allow for monitored Iranian purchases for its remaining nuclear programs and civilian industries while banning the rest. A potential way to do this is seen in the creation of the humanitarian goods channel created under the interim deal. In the case of a long term provision limiting nuclear related goods, at the beginning of the period of the comprehensive solution, a procurement channel should be established for controlled items used in Iran's nuclear programs. The list of items would be established by mutual agreement and would include major nuclear facilities, nuclear components, and nuclear and nuclear-related dual-use goods.[18] Iranian civil industries needing these goods could also procure them through this channel. The channel is best established in a United Nations Security Council resolution that will be binding on all states. The resolution should create a committee and a Panel of Experts to oversee the implementation of the resolution. Procurements of listed items outside this channel would be banned and considered illicit nuclear trade. This condition would

[18] For more explanation of requirements to prevent Iranian illicit trade under an agreement and a discussion of the types of dual-use goods both on and not on control lists, used in Iran's centrifuge program, see: David Albright, Andrea Stricker, and Houston Wood, *Future World of Illicit Nuclear Trade: Mitigating the Threat* (Washington, D.C.: ISIS, July 29, 2013). http://isis-online.org/uploads/isis-reports/documents/Full_Report_DTRA-PASCC_29July2013-FINAL.pdf

also have the benefit of more clearly identifying procurements from North Korea to Iran as illicit.

A key goal of the negotiations must also be to give the IAEA visibility of, and the right to inspect, future imports of proliferation-sensitive goods by Iran as agreed under a comprehensive solution. It will need to ensure that the goods are either destined for a legitimate nuclear or civilian end-use. To ensure the completeness of Iran's declarations of imports, the IAEA will also need secure access to information related to the domestic production of key nuclear related equipment, components and raw materials.

Iran should also commit not to export or otherwise transfer nuclear materials, reactors, centrifuges, reprocessing equipment, other nuclear facilities or equipment, or the means to make such equipment or facilities to any state, company, or other entity.

Appendix: January 2014 ISIS Comprehensive Solution Model

In parallel to Iran/IAEA negotiations, the P5+1 is negotiating the provisions of the comprehensive solution. The U.S. negotiators will face very tough resistance from Iran as they seek to achieve a long-term comprehensive agreement that will limit Iran's most dangerous nuclear programs and ensure adequate verification.

The Joint Plan of Action does not grant Iran the right to enrich uranium, but it accepts that in a comprehensive agreement Iran will maintain a centrifuge program. However, Iran conceded that for a period to be agreed upon, any such program would be subject to limitations on the number of centrifuges, the location of any centrifuge plants, the level of enrichment, and the size of stocks of enriched uranium. It also agreed that the program must be consistent with "practical needs" within "mutually agreed parameters."

In negotiating limitations on Iran's centrifuge and other nuclear programs and adequate verification requirements, the United States should be guided by several key guidelines:

- Extending breakout times significantly to at least 6-12 months, reflecting the numbers and types of centrifuges and stocks of low enriched uranium under a comprehensive solution. This requires that Iran remove over 14,000 centrifuges at the Natanz and Fordow enrichment sites. In the longer term, a fraction of these centrifuges would be stored or dismantled for use as spares and the rest would be destroyed;
- Reducing and limiting Iran's stockpiles of enriched uranium and natural uranium. In the case of near 20 percent low enriched uranium, these stocks would need to be further reduced from the level expected at the end of the interim period;
- Blocking Iran's plutonium route to nuclear weapons;
- Reducing significantly Iran's ability to build secret facilities to enrich uranium or separate plutonium;
- Ensuring that Iran commits to stopping its illicit procurements of goods for its nuclear programs;
- Achieving that any limits on Iran's nuclear programs have a duration of at least 20 years
- Implementing adequate verification that goes beyond the Additional Protocol; and
- Conditioning any end to UN Security Council and U.S. economic sanctions on Iran addressing all of the IAEA's concerns, in particular those about Iran's past and possibly on-going nuclear weapons efforts.

The following are a list of provisions that would meet the above guidelines and form the basis of a comprehensive solution able to protect adequately national security interests. For more detail, the reader is referred to the ISIS report on the necessary elements of a comprehensive solution. For background information, the reader is referred to the main ISIS website and its Iran-specific website.

Conditions without a defined duration

- The Arak reactor complex will be upgraded to a light water reactor using low enriched uranium fuel.
- Iran will not reprocess any irradiated fuel or build a facility capable of reprocessing.
- Iran will not enrich above 5 percent in the isotope uranium 235, and will not produce stocks of enriched uranium that exceed in quantity the needs of its civilian program, noting that it has long term LEU fuel delivery agreements with Russia and would be expected to have additional ones with foreign reactor vendors after the conclusion of a comprehensive solution.
- Iran will commit not to procure goods for its nuclear programs abroad in a manner that is considered illicit ("illicit nuclear trafficking or trade").

Conditions and parameters with a defined duration of 20 years

- Iran will have only one enrichment site, the one at Natanz. The Fordow site will be shut down or converted into a non-centrifuge-related site.
- Centrifuge research and development will only be conducted at the one enrichment site. All centrifuge testing, with or without nuclear material, will occur at this site. Centrifuge research and development will be limited to centrifuges with the theoretical equivalent enrichment output of no more than five separative work units in kilograms uranium (swu) per year. This is about the level of the IR-2m centrifuge.
- Major centrifuge component manufacturing and storage locations will be limited in number and identified.
- Centrifuge assembly will occur only at the one enrichment site.
- The number and type of centrifuges will be limited to ensure that breakout times are measured in many months and will be a minimum of six to twelve months at all times.
- In order to define a cap in practical terms, it is necessary to first consider the case where only IR-1 centrifuges are enriching at the Natanz Fuel Enrichment Plant. In the case of a six month breakout time, a cap on total number of IR-1 centrifuges at the Natanz site is derived from the condition of the historical IR-1 centrifuge operations at the Natanz Fuel Enrichment Plant and the size of Iran's residual stock of 3.5 and near 20 percent LEU. The estimated cap is about 4,000 IR-1 centrifuges in the case of a breakout estimate of six months and fewer centrifuges in the case of a 12 month breakout estimate.
- Because Iran may seek to replace the IR-1 centrifuges with more capable ones, a more general enrichment cap is derived from the cap on IR-1 centrifuges developed above and is approximately 3,600 swu/year. This value serves as a general enrichment cap regardless of the actual enrichment capacity of any centrifuge that would replace the IR-1 centrifuge in the future. If Iran deployed IR-2m centrifuges, for example, the parties would need to agree upon an average centrifuge enrichment value before deriving the number of IR-2m centrifuges needed to produce 3,600 swu/yr. For example, if an IR-2m centrifuge has an average enrichment output of 4 swu per year, then the cap would be 900 IR-2m centrifuges. If Iran deploys any other enrichment technology, such as laser enrichment, it and any centrifuge plant would need to have a total enrichment output at this cap or below.

- In the case of the IR-1 centrifuges, centrifuge manufacturing would be limited to the replacement of broken centrifuges, if no spares exist (see below). For example, in the case of IR-1 centrifuges, a stock of many thousands of uninstalled centrifuges would be stored and then drawn upon to replace broken ones. Thus, Iran would agree not to build any IR-1 centrifuges until this stock is exhausted.[19] Centrifuge manufacturing of new centrifuges in the case of the IR-2m centrifuge, if used for enrichment at the Natanz Fuel Enrichment Plant, would be unnecessary, at least initially, because any broken ones could be drawn from a surplus stock of them. In the case of new centrifuges, Iran will not build more centrifuges than allowed to be installed under the above enrichment cap of 3,600 swu/year and would build more only to replace broken ones.
- When the long term agreement takes effect, centrifuges and all associated cascade equipment in excess of the cap would be turned off, so that no centrifuges are operating. Centrifuges would be turned off in a controlled manner so as to limit centrifuge damage.
- Right after the comprehensive solution is implemented, excess centrifuges and the cascades containing them would be disabled in a manner so as to require at least one month to restart any disabled cascades.
- Excess centrifuges and associated cascade piping and equipment will be scheduled for removal from Natanz and Fordow and stored under IAEA monitoring. These centrifuges and associated cascade items will be stored at an agreed-upon site under IAEA monitoring, pending their use as replacements of broken centrifuges and cascades or their destruction under monitoring.
- Iran will not build any conversion lines that can convert enriched uranium oxide into hexafluoride form.
- LEU stocks will be limited, based on a realistic civil justification.
    - With regard to near 20 percent LEU, Iran will not possess any such LEU in hexafluoride form and its total stock in unirradiated oxide form including in fresh fuel elements and assemblies will be reduced rapidly to less than the equivalent of 100 kg (better if lowered to 50 kg) of near 20 percent LEU hexafluoride soon after the start of the implementation of the comprehensive solution. During the term of the agreement, this stock will be reduced further to below the equivalent of 50 kg of near 20 percent LEU hexafluoride.
    - Iran will not possess more than the equivalent of 1-5 tonnes of unirradiated, less than five percent LEU hexafluoride, almost all of which should be in oxide form. Of this total LEU inventory, Iran will possess no more than 1 tonnes LEU hexafluoride at any one time; in essence this cap requires Iran to convert LEU hexafluoride into oxide form.[20]
    - LEU in excess of these caps will be blended down to natural uranium or shipped abroad for storage or fuel manufacturing. In practice, this step is likely to be

[19] Broken centrifuges will be replaced with centrifuges of the same type. This should mean, for example, that an installed IR-1 centrifuge would be replaced with an IR-1 centrifuge of the same design and enrichment capacity as the one removed. A broken centrifuge is defined as one that has a rotor assembly incapable of spinning under power and cannot be repaired.
[20] The limits on the size of LEU stocks are lower than in the original proposal.

necessary only if Iran does not find a way to use this LEU in reactors during the next decade.

- Uranium mining, milling, and conversion facilities will be limited in throughput to the actual need for enrichment or other mutually agreed upon use. Natural uranium stocks will be limited.
- At the beginning of the period of the comprehensive solution, a procurement channel will be established for items needed in Iran's nuclear programs. The list of items will be established by mutual agreement and will include major nuclear facilities, nuclear components, nuclear and nuclear-related dual-use goods, and other sensitive items such as those on watch lists. Procurements of listed items outside this channel will be banned and considered illicit nuclear trade. This condition will also have the benefit of more clearly identifying procurements from North Korea to Iran as illicit. Iran will declare to the IAEA the key exports received and these items will be subject to IAEA verification.
- Iran will not export or otherwise transfer nuclear materials, reactors, centrifuges, reprocessing equipment, other nuclear facilities or equipment, or the means to make such equipment or facilities to any state, company, or other entity.[21]
- By the end of the period in which the comprehensive solution will be in force, Iran will implement an export control system in line with the requirements of the four main export control regimes (lists and guidance) and submit a comprehensive report to the 1540 Committee on Iran's implementation of the resolution. Iran will also commit not to export or otherwise transfer reprocessing or enrichment technologies or goods to any state or non-state actor after the comprehensive solution period ends.

[21] A model condition developed by ISIS: The state of concern agrees not to transfer to any state or entity whatsoever, or in any way help a state or entity obtain, nuclear weapons or explosive devices, or components of such weapons; nuclear material; nuclear know-how or technology; or equipment, material, goods, technology designed for, prepared for, or that can contribute to the processing, use, or production of nuclear materials for nuclear weapons or in sanctioned nuclear programs.