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STALL SPEED: ASSESSING DELAY OF THE IRANIAN NUCLEAR PROGRAM VIA ISRAELI MILITARY STRIKE

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The possibility of Israeli military action against the Iranian nuclear program has existed since at least 2002. However, beginning in the fall of 2011, Israeli rhetoric and international concerns about military action against Iran have reached unprecedented levels. Israeli Prime Minister Benjamin Netanyahu and Defense Minister Ehud Barak began to proclaim that Iran was nearing a "zone of immunity" to Israeli attack and therefore Israel would have to act soon.[1] In contrast, former heads of Israel's foreign and domestic intelligence services question the utility of such an attack.[2]

Evaluating the utility of military action requires an understanding of the likely costs and benefits. One of the key components for assessing the utility of Israeli military action against the Iranian nuclear program is how much an attack will delay the Iranian program. In early 2012 a number of estimates of the effect of such a strike appeared in the media. According to some reports there are Israeli estimates that such a strike could produce a delay of at least five years.[3] In contrast, there are reports that U.S. estimates indicate such a strike could only delay the program for a year and even subsequent U.S. strikes would only delay it another two years.[4]

The high discrepancy in these estimates is a serious problem for public debate, particularly in Israel, as a strike may not be worth the consequences if it produces only a year delay but might be worth it if it produced five years delay. Unfortunately the methodology for producing these numbers is completely opaque. Previous experiences with government assessment suggest that the methods used to produce these estimates may lack serious rigor as well. Indeed, none of the publicly revealed estimates even provide a clear definition of what "delay" even means.

This essay is an attempt to provide a transparent and relatively rigorous assessment of what a strike is likely to accomplish in terms of delay. It will inevitably include caveats and uncertainties but by clearly establishing a transparent range of estimates based on unclassified information the public will at least get a sense for what is likely and where a change in assumptions can change the length of delay. [5]

The first step is to define delay, which is a nebulous term in this context. Here the best specific definition is based on the time for Iran to produce sufficient weapons grade uranium (WGU) for one nuclear weapon should it decide to do so. As discussed more below, Iran is at or very near having the capability to quickly enrich enough WGU, defined here as 90%+ enriched, for one nuclear weapon. So delay will be defined as the difference in time between how long it would take Iran to produce enough material for a single nuclear weapon absent a strike and how long it would take after a strike (again, should it decide to do so). This says nothing about weapon design or delivery systems, but an Iran that has enough WGU for a weapon without a deliverable device is still qualitatively different from an Iran that has a delivery system but no WGU.

This basic definition must then be amplified by looking at the specifics of Israeli military capabilities against the Iranian nuclear program. Israel had for years a relatively robust military option against key Iranian nuclear facilities (in this case this is the uranium conversion facility and fuel fabrication plant at Isfahan, a smaller conversion lab in Tehran, and the enrichment facility at Natanz along with potentially some industrial sites dedicated to centrifuge production).[6] However, the Iranian Fordow facility, buried under 80 or more meters of rock, presents a substantially more difficult military target.[7] It may not even be possible for Israel to inflict substantial damage on this facility, which has been rapidly developed by Iran since the fall of 2011 (and thus is the prompt for the increasing bellicosity of Israeli rhetoric). As Fordow can potentially be used for the production of WGU, from an Israeli perspective delay will be more specifically defined as the difference in time for Iran to produce fissile material at Fordow absent a strike against all other key Iranian nuclear facilities and following such a strike. If that difference is small, a strike makes no sense, while if it is large such a strike may be worth the consequences.

The critical variable then is how quickly Iran can enrich sufficient uranium for a single bomb at Fordow. A key term of art for enrichment is the separative work unit (SWU), which provides a benchmark for the effort needed for separating uranium. According to assessments by the Institute for Science and International Security (ISIS) as well as my own calculations, Iran has been able to sustain slightly less than 1 SWU per centrifuge in the Natanz pilot enrichment plant, which is similar in scale to Fordow, though they have not yet been able to maintain this level at Fordow.[8] According to the International Atomic Energy Agency (IAEA) inspection in February 2012, Iran has installed almost 700 centrifuges at Fordow. Half of those were installed since the previous inspection in November, suggesting Iran can install around 350 centrifuges every 3 months.[9]

However, the August 2012 IAEA report indicates Iran has increased the rate of installation, with just over 2,100 centrifuges at Fordow.[10] Yet only about 700 of those centrifuges are operating, which raises questions about how functional the other 1400 are. They could be missing key components, and thus a sort of “Potemkin cascades.” Alternately, Iran may just not feel the need to operate at this time. For the base case, I will assume that these 1400 are not functional, but will include a scenario where they are functional in subsequent analysis. For the base case then, I assume 700 centrifuges operating at roughly 1 SWU each, a total of 700 SWU.

A good but not great nuclear design (one that makes efficient use of neutrons) would require somewhere between 15 and 25 kilograms (kg) of WGU. The higher figure is the more commonly used one but a pessimist would note that the lower figure is feasible. Using a uranium hexafluoride (the form of uranium used for enrichment) feed at the natural level of enrichment, which is less than 1%, producing this much WGU would require roughly 3000 to 5000 SWU. Dividing these numbers by the 700 SWU annually at Fordow we just calculated, it would take Iran 4-7 years to produce enough WGU for one weapon. Note this assumes Iran has a good product to feed ratio (in other words they are able to enrich effectively without too many problems that cause centrifuges to make less efficient use of feed), which analysis by both ISIS and myself suggests Iran has not been able to maintain. Yet it is not implausible to assume that they could in the near futute.[11] It also assumes Iran wants to be fairly efficient in its use of uranium hexafluoride (UF6), so I assume .3% tails (the enrichment level of the UF6 residual).

However, if those same centrifuges at Fordow were fed with UF6 that had already been enriched to just below 20% it would only require about 280 to 470 SWU to produce the same 15-25 kg of WGU (again assuming .3% tails, which is probably not realistic). Dividing by the same 700 SWU annually, this means Iran could have a bomb's worth of WGU in about 5-8 months. It would need a stockpile of between 105 and 180 kg of this 20% enriched UF6 to produce this 15-25 kg of WGU. As of May 2012, the IAEA reported Iran had a stockpile of about 145 kg of 20% enriched uranium.[12] However, Iran also began converting 20% enriched UF6 into fuel plates for the Tehran research reactor, meaning that in order to be further enriched for use in a weapon this material would have to be converted back to UF6.[13] By August 2012, Iran had produced 189 kg of 20% enriched UF6 but only retained either 91 or 116 kg as UF6, the rest being fed into the conversion process.[14]

Iran is unlikely to be as frugal and efficient in its use of 20% enriched UF6 as the above implies. If they choose not to be as efficient (e.g. because they have a somewhat larger stockpile) they could reduce the time. For example, if the Iranians chose 3.5% tails as acceptable this would require roughly 130-210 kg of 20% enriched UF6 to produce 15-25 kg of WGU metal but only about 160-260 SWU. In other words the time would be reduced to about 3-4 months. I will use this figure, which is likely more representative, for subsequent calculations.

Iran also has a stockpile of just over five tons of UF6 that has been enriched to up to 5% with the actual level of enrichment being about 3.5%.[15] If we calculate the timeline using this material as feed for Fordow, it would require about 750 to 1250 SWU to produce enough material for one bomb, assuming just below 1% tails. With 700 centrifuges this would take about 1 to 2 years. For maximum delay then Israel must destroy this stockpile as well.

It is clear then that an Israeli strike this fall that destroys Iran's existing stockpile of 20% and 3.5% enriched uranium along with the facilities at Isfahan and Natanz would produce a substantial delay in the timeline for Iran to produce enough WGU for a single bomb using just the centrifuges at Fordow and natural (i.e. unenriched) UF6. For this base case, if we assume 15 kg WGU for a bomb, then the delay is essentially 4 years minus 3 months or 45 months. If we assume 25 kg it is essentially 7 years minus 4 months or 80 months.

Note that it is crucial that Israel destroy as much of the 20% enriched stockpile as possible, as this is the key to Iran's option to rapidly produce WGU at Fordow. If Iran were to concentrate a sufficient stockpile of 20% enriched UF6 at Fordow then an Israeli strike would produce little in the way of delay. This also assumes that an Israeli strike destroys the stockpile, which is small in size and therefore harder to more precisely target inside facilities.[16]

While the bulk of this stockpile appears to be at Natanz, Tehran, and Isfahan, the May 2012 IAEA report indicates Iran probably has about 35 kg of 20% enriched UF6 at Fordow along with an unclear amount of UF6 enriched to 3.5%. By August 2012 the20% enriched stockpile at Fordow had increased to about 65 kg as the facility has been producing roughly 2 kg a week using the 3.5% stockpile as feed. It is not clear how much of this has been used to produce fuel plates, but it seems to be no more than 50 kg.[17] This stockpile at Fordow, which appears to be somewhere between 15 kg and 65 kg, would speed Iranian production to a weapon after a strike that destroyed other stockpiles and facilities.

If we assume there is 65 kg of 20% enriched and 200 kg of 3.5% enriched UF6 at Fordow, this could be used to produce nearly 13 kg of WGU using only about 340 SWU.[18] This translates to about six months of enrichment time. Iran would then have to produce somewhere between 2 and 12 kg more using natural uranium feed, which would require roughly another 385 to 2320 SWU or roughly 6-40 months. Adding the six months for enriching the other material, this would be roughly 1-4 years. The delay would therefore be less than the base case, and is sensitive to assumptions about how much WGU Iran needs for a bomb. The delay would range from a fairly short 9 months (12 months minus 3months) to 42 months (46 months minus 4 months).

However, if there is only 15 kg of 20% and 200 kg of 3.5% enriched UF6 at Fordow, the timelines are longer. These stockpiles together could produce about 6 kg of WGU using about 230 SWU. This would take about 4 months. The remaining 9 to 19 kg of WGU would require 1740-3670 SWU to produce using natural uranium feed, or roughly 2.5-5 years. The timeline for delay would thus be quite long, ranging from about 31 months (34 months minus 3 months) to 60 months (64 months minus 4 months).

Having established these base cases, we can then explore some other assumptions. First, Iran could actually be able to operate all of the roughly 2100 centrifuges at Fordow. At 1 SWU per centrifuge, this would cut the timelines above by two-thirds. These two variations, 700 centrifuges and 2100 centrifuges operating at 1 SWU each, are summarized below.

Timeline (1 SWU/centrifuge)	Timeline w/o strike	Timeline w/strike	Delay
Fordow base case- 700 centrifuges	3 to 4 months	4 to 7 years	45 to 80 months
Fordow w/700 centrifuges and 65 kg 20% feed	3 to 4 months	12 to 46 months	9 to 42 months
Fordow w/700 centrifuges and 15 kg 20% feed	3 to 4 months	34 to 64 months	31 to 60 months
Fordow base case- 2100 centrifuges	4 to 6 weeks	16 to 28 months	15 to 26 months
Fordow w/2100 centrifuges and 65 kg 20% feed	4 to 6 weeks	4 to 15 months	3 to 14 months
Fordow w/2100 centrifuges and 15 kg 20% feed	4 to 6 weeks	11 to 21 months	10 to 19 months

These are timelines for a strike in the very near term (fall of 2012) but Iran will likely continue to install centrifuges in Fordow unless its ability to do so is reduced by the strike. If it is not, Iran could have 2400 to 2784 centrifuges at Fordow by the end of the year, with the latter being the maximum capacity. This would cut the time to produce WGU substantially if they could continue to operate them at 1 SWU each (something Iran has not managed at the larger Natanz facility). While these centrifuges are installed, the existing centrifuges could continue enriching to 20%. Iran could easily have 55 to 105 kg of 20% enriched UF_6 at Fordow by the end of the year on its current trajectory.

Assuming Fordow is at maximum capacity and using that 20% enriched stockpile, Iran could produce roughly 7 to 13 kg of WGU using about 75 to 145 SWU, which would take 2-3 weeks. If Iran also had 200 kg of the 3.5% enriched UF_6 at Fordow it could produce an additional 5 to 6 kg of WGU using about 240 to 280 SWU, which take an additional 4-5 weeks.[19] This would give Iran roughly 12 to 19 kg of WGU in 6-8 weeks. If the high end estimate of 19 kg is combined with the pessimistic estimate of how much WGU Iran needs for a bomb (15 kg), it is clear that the delay would be trivial, roughly 5 weeks (8 weeks minus 3 weeks). If the high end estimate is combined with the normal 25 kg of WGU for a bomb, the delay is better, as Iran would have to produce an additional 6 kg of WGU with natural uranium feed, requiring about 1160 SWU or about 22 weeks for a total delay of 27 weeks.

If the lower estimate of 12 kg is used, then Iran would need to produce the remaining 3 to 13 kg of WGU with natural uranium feed. This would require about 580 to 2500 SWU or about 11 to 47 weeks, for a total time to produce enough WGU for one bomb of 17 to 53 weeks. Delay in this scenario would be 14 (17 weeks minus 3 weeks) to 50 weeks (53 minus 3 weeks).

The key variables are both the number of centrifuges and the stockpiles of enriched UF6, along with the assumption about required amount of WGU. Iran has substantial control over its UF6 stockpile and could shift more of the 20% and 3.5% stockpile to Fordow. Thus in the example above Iran might have more 3.5% enriched UF6 at Fordow so that it could create a larger stockpile of 20% there and/or it could consolidate all of the 20% enriched UF6 there. Iran could also increase or decrease the rate at which it is converting UF6 to fuel plates. Iran could thus have more than 150 kg at Fordow by the end of the year, or it could have substantially less, with corresponding impacts on delay.

An Israeli strike may also limit Iran's ability to put centrifuges in Fordow. Israeli strikes may, in addition to the facilities at Tehran, Isfahan, and Natanz, destroy key manufacturing locations for centrifuges. Additionally, Iran has not proved capable of reliably producing certain centrifuge components, such as maraging steel and ring magnets, so damaging or destroying stockpiles of these components would force Iran to seek these materials in greater volumes on the international black market (at least if export restrictions on these items remain in place).[20] This would in turn expose it to greater risk of covert action programs that are alleged to introduce faulty centrifuge components to the Iranian supply chain.[21]

It is unclear if Israel has good intelligence on key manufacturing and storage areas for centrifuge components. But the U.S. government is known to monitor and identify locations associated with centrifuge manufacture in order to apply various sanctions to them. These were last updated in November 2011, providing addresses for, among others the Iran Centrifuge Technology Company, which is known by the Farsi acronym TESA and "plays a crucial role in Iran's uranium enrichment nuclear program. It is involved in the production of IR-1 centrifuges, the type of centrifuge Iran has used to enrich uranium…"[22] It can be safely assumed then that Israel can target at least some key manufacturing and storage sites. TESA's two listed locations, for example, are in Tehran and Isfahan, near where Israelis strikes would be directed anyway.

Estimating the delaying effect of strikes on centrifuge component manufacturing and storage sites is more difficult than the more straightforward effect on enrichment timelines. If these strikes eliminate the crucial components that Iran cannot produce itself, then Iran may be stuck with only the centrifuges assembled in Fordow for many months or even years. If the strikes miss some or all of these critical components but still destroy crucial facilities that Iran uses to manufacture components like aluminum rotors, then there will likely be a transient delay of perhaps a few months as other facilities are brought online. The latter would potentially even enable Iran to create another Fordow like facility elsewhere in the country though this would take time.

Likewise the Israelis may choose to strike Fordow's entrance and ventilation system. Even if this produced little or no damage to the centrifuge facility itself such a strike could limit access, making the facility unusable for weeks or perhaps even months. This would add to any delay.

Finally, striking the uranium conversion facility and fuel fabrication facility at Isfahan and a smaller lab scale facility in Tehran will limit the Iranian ability to convert any enriched UF6 back into the uranium metal needed for a bomb. This would force them to rebuild to make use of any enriched UF6 though it might not add substantially to the timeline above as this rebuilding is relatively straightforward and does not require anything other than industrial chemical processes. It would also curtail the ability of the Iranians to produce additional UF6 but they have large stockpiles of natural (i.e. not enriched) UF6 so this is not a substantial delay.

The foregoing analysis demonstrates that the Israeli military option is a rapidly wasting asset in terms of inflicting delay. It should be clear then that an Israeli strike in the near term has the possibility of inflicting a substantial delay on the Iranian timeline to produce enough highly enriched uranium for a single bomb. Yet much depends on the assumptions about the key variables above.

However, the recently publicized U.S. and Israeli estimates seem off. The U.S. estimate of one year delay seems to be at the very pessimistic end of the spectrum, with strikes having little impact on the ability to add centrifuges at Fordow and the Iranians needing only 15 kg of highly enriched uranium. In contrast, the Israeli estimate of at least five years seems wildly optimistic. The most plausible estimate for a strike in the fall seems to be that provided by the third case in the table above plus some delay from striking Fordow's entrance along with centrifuge component manufacturing and storage. This produces a likely range for delay of just under one to two years, with just over two and a half years (the upper end estimate from the second case in the table) seeming to be the realistic upper bound.

There are a number of assumptions built into the analysis above and many of them could prove wrong. For example, Iran may not be able to maintain roughly 1 SWU per centrifuge or it may run into other product to feed ratio problems. This would change the timelines both with and without a strike for any of the scenarios outlined above.

For example, we can hypothesize that Iran will only be able to maintain .66 SWU per centrifuge as operations at Fordow expand. This would increase each of the timelines by roughly 50% as noted in the table below. This has substantial impact on the magnitude of delay for some cases, but little effect on the delay for a hypothetical strike once Fordow is at maximum capacity and has a substantial stockpile of 20% enriched UF6. In this case delay would be roughly 2 to 9 months.

Timeline (.66 SWU/centrifuge)	Timeline w/o strike	Timeline w/strike	Delay
Fordow base case- 700 centrifuges	4 to 6 months	6 to 10.5 years	68 to 120 months
Fordow w/700 centrifuges and 65 kg 20% feed	4 to 6 months	18 to 69 months	14 to 63 months
Fordow w/700 centrifuges and 15 kg 20% feed	4 to 6 months	51 to 96 months	47 to 92 months
Fordow base case- 2100 centrifuges	6 to 9 weeks	24 to 42 months	22 to 40 months
Fordow w/2100 centrifuges and 65 kg 20% feed	6 to 9 weeks	6 to 22 months	4 to 20 months
Fordow w/2100 centrifuges and 15 kg 20% feed	6 to 9 weeks	16 to 31 months	14 to 29 months
Fordow w/2784 centrifuges and 105 kg 20% feed	5 to 8 weeks	12 to 45 weeks	7 to 37 weeks

The foregoing says little about the costs of Israeli military action but it at least provides a transparent basis for estimating one of the key benefits. It also says little about a sustained U.S. campaign, which would likely be able to destroy Fordow and more, perhaps most, centrifuge component sites.[23] Such a campaign would be more effective, but does not face the same potential time pressure to act soon that the Israelis face.

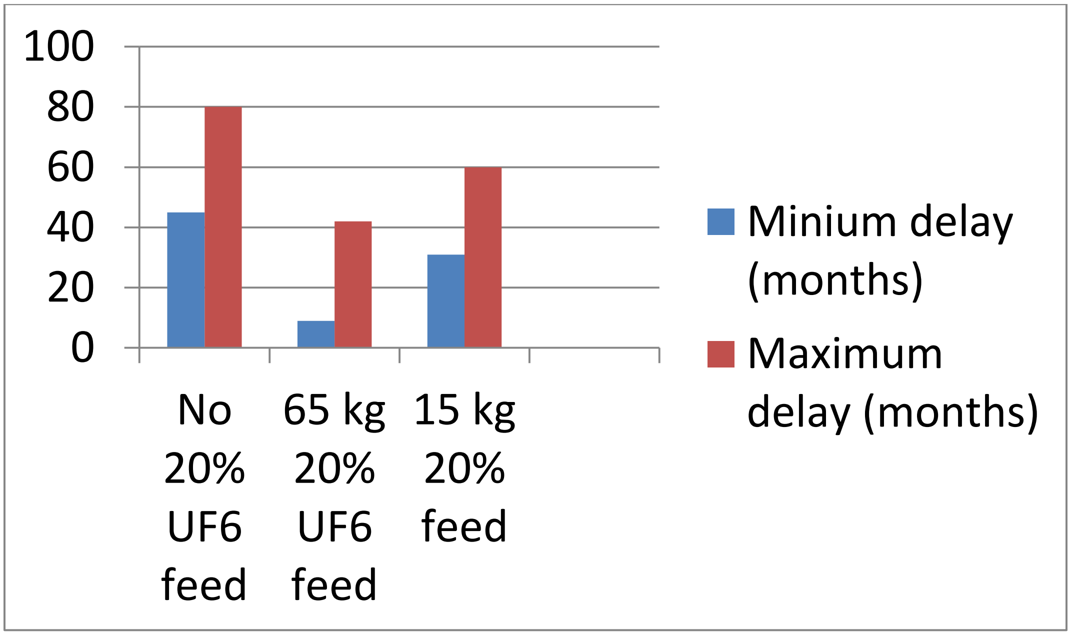

Chart 1: Delay ranges for 700 centrifuges at 1 SWU each

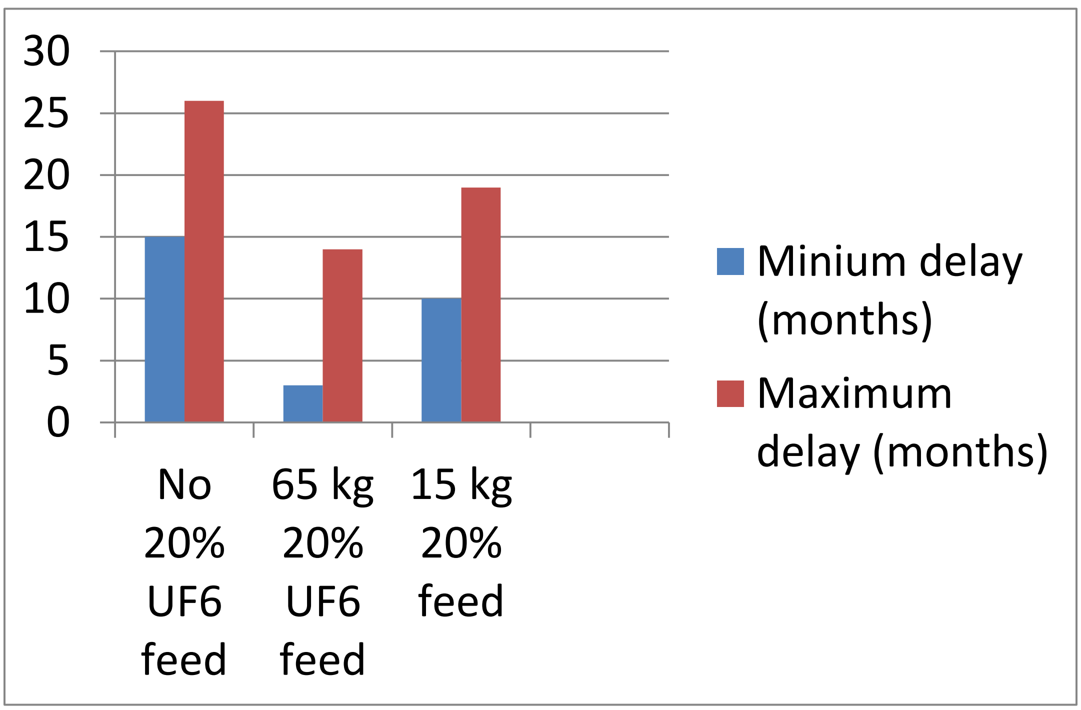

Chart 2: Delay ranges for 2100 centrifuges at 1 SWU each

[1] Ethan Bronner, "2 Israeli Leaders Make the Iran Issue Their Own," *New York Times*, March 27, 2012 and Herb Keinon, "PM: Iran Strike Worthwhile, Even to Delay Nuke Program," *Jerusalem Post*, August 16, 2012.

[2] Yaakov Lappin and Yaakov Katz, "Dagan Supports Diskin's Iran Comments," *Jerusalem Post*, April 30, 2012.

[3] Jeffrey Goldberg, "Israelis Grow Confident Strike on Iran's Nukes Can Work," *Bloomberg*, March 19, 2012.

[4] Mark Mazetti and Thom Shanker, "U.S. War Game Sees Perils of Israeli Strike Against Iran," *New York Times*, March 19, 2012.

[5] The discussion of enrichment draws heavily on Allan Krass, et al., *Uranium Enrichment and Nuclear Weapon Proliferation* (London: Taylor and Francis, 1983).

[6] Whitney Raas and Austin Long, "Osirak Redux? Assessing Israeli Capabilities to Destroy Iranian Nuclear Facilities," *International Security*, v.31 n.4 (Spring 2007).

[7] Austin Long, "Can They? How Israel Can Pull Off a Successful Strike Against Iran's Nuclear Program," *Tablet* (November 2011)

[8] David Albright and Christina Walrond, "Performance of the IR-1 Centrifuge at Natanz," Institute for Science and International Security, October 18, 2011 and David Albright, Paul Brannan, and Christina Walrond, "ISIS Analysis of IAEA Iran Safeguards Report," *Institute for Science and International Security*, February 24, 2012. The calculations can be done by assessing enrichment output reported by the IAEA at the different facilities.

[9] International Atomic Energy Agency, "Implementation of the NPT Safeguards Agreement and Relevant Provisions of Security Council Resolutions in the Islamic Republic of Iran," February 24, 2012 (hereafter IAEA February 2012), pp 5-6.

[10] International Atomic Energy Agency, "Implementation of the NPT Safeguards Agreement and Relevant Provisions of Security Council Resolutions in the Islamic Republic of Iran," August 30, 2012 (hereafter IAEA August 2012), p. 14. I assume Iran is not close to solving the operational issues that appear to have plagued their more advanced centrifuge designs. See IAEA August 2012, p. 5.

[11] Albright and Walrond, pp. 2-4.

[12] International Atomic Energy Agency, "Implementation of the NPT Safeguards Agreement and Relevant Provisions of Security Council Resolutions in the Islamic Republic of Iran," May 25, 2012 (hereafter IAEA May 2012), p. 3.

[13] IAEA May 2012, p. 8.

[14] See IAEA August 2012, p. 8 and p. 13. The reason for the discrepancy in numbers is unclear.

[15] IAEA August 2012, pp. 4-5. Iran has produced nearly 7 tons of UF6 enriched to up to 5%.. However, Iran has then further enriched about 1.5 tons of that stockpile to produce its 20% enriched stockpile, leaving a stockpile of just over five tons of up to 5% enriched.

[16] Destroying UF6 means to scatter the UF6 so that it reacts with water vapor in the atmosphere. According to Argonne National Laboratory this would reduce the UF6 to "corrosive hydrogen fluoride (HF) and a uranium-fluoride compound called uranyl fluoride..." This would prevent further enrichment of the uranium as well as make recovery of the material or centrifuges more difficult if not impossible. See http://web.ead.anl.gov/uranium/guide/uf6/propertiesuf6/index.cfm (accessed August 15, 2012).

[17] IAEA August 2012, p. 5.

[18] I assume the Iranians would use the roughly 53 kg of 3.5% enriched tails left from enriching the 20% enriched UF6 along with the 200 kg stockpile of 3.5% enriched UF6 for a total of 253 kg.

[19] I assume the Iranians would use the roughly 45 to 85 kg of 3.5% enriched tails left from enriching the 20% enriched UF6 along with the 200 kg stockpile of 3.5% enriched UF6 for a total of 245 to 285 kg.

[20] David Albright and Andrea Stricker, "Iran's Nuclear Setbacks: A key for U.S. diplomacy," online at http://iranprimer.usip.org/blog/2011/jan/18/iran%E2%80%99s-nuclear-setbacks-key-us-diplomacy (accessed August 16, 2012)

[21] See "Covert Operations in Iran," December 30, 2010, online at http://www.stimson.org/spotlight/covert-operations-in-iran/ (accessed August 16, 2012).

[22] U.S. Treasury Department, "Fact Sheet: E.O. 13382 Designations on Iran," November 21, 2011, online at http://www.treasury.gov/resource-center/sanctions/OFAC-Enforcement/Documents/11212011_iran_wmd_factsheet.pdf (accessed August 16, 2012).

[23] There is some debate about the U.S. ability to destroy Fordow, but there is reason to believe that a sustained U.S. campaign would destroy the facility. See Joby Warrick, "Iran's Underground Nuclear Sites not Immune to U.S. Bunker-busters, Experts Say," *Washington Post*, February 29, 2012.