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Calculating the Capacity of Fordow

The 16 November 2009 report of the International Atomic Energy Agency (IAEA) was its first after the agency's initial inspection of Iran's recently declared Fordow Fuel Enrichment Plant (FFEP), just north of Qom. On November 23, we published in the *Bulletin of the Atomic Scientists* a short technical analysis of what the new plant reveals about Iran's nuclear weapons potential and its implications for international policy. In summary, we concluded that the timing of the construction and announcement of the facility did not *prove* an Iranian intention to deceive the agency but certainly raises many troubling questions. The facility is far too small for a commercial enrichment facility, raising additional serious concerns that it might be intended as a covert facility to produce highly enriched uranium (HEU) for weapons. But we also argued that the facility is actually too small to be of great use to a weapons program. A quite plausible explanation is that the facility was meant to be one of several covert enrichment facilities and simply the only one to be discovered. We believe, however, that it is significant that the Iranians assured the agency that they "did not have any other nuclear facilities that were currently under construction or in operation that had not yet been declared to the Agency"[1] because any additional facilities uncovered in the future will be almost impossible to explain innocently. This, however, does not preclude Iran from making a decision to construct new enrichment facilities in the future.

Our *Bulletin* publication was based primarily on information available in the press and in IAEA reports. Much of our discussion of the legality and political significance of the FFEP hinged on the timing of the construction, specifically – did Iranian actions violate even Iran's narrow interpretation of their obligations to declare new facilities to the IAEA? We argued that the plant is too small to be useful to enrich fuel for nuclear reactors. Contrary to most analyses, we also argued that the FFEP was too small even to make much sense as a source of nuclear weapon material. These statements are based on a technical analysis of Fordow's capabilities and specifically 3 main estimated timelines: (1) it will take about 90 years for the 3,000 IR-1 centrifuges, as declared by Iran in its design information to the IAEA, to enrich enough natural uranium to fuel a typical 1000-megawatt reactor for a year, (2) it

[1] GOV/2009/74, Art. 16

will take about four years for those same machines to enrich enough natural uranium to a bomb's worth of HEU, and (3) it will take about one year to enrich enough LEU to HEU for a bomb. All three calculations are based on estimates of the performance of the IR-1that were not included in the *Bulletin* article but are presented here.

We believe it is important to go into some detail about how we arrived at that result because our estimate of the effective capacity of Iran's centrifuges is smaller, by a factor of three or four or more, than typically cited in the literature. We believe that simple rules of thumb sometimes used to estimate Iran's nuclear weapon breakout capability can seriously overestimate the threat. In this *Issue Brief*, we show in detail our calculations and state explicitly our assumptions and assertions.

Most analyses that have addressed the question of estimating the enrichment capacity of Iran's facilities, either at Natanz or Fordow, estimate the capacity of an individual centrifuge of the type installed in the facility (or in the case of Fordow, expected to be installed) and then multiply by the number of centrifuges, which should yield the total capacity. There are two problems with this approach. First, the capacity of the individual centrifuges is unknown and, second, linking centrifuges together is more complicated than can be represented by simple multiplication. We shall deal with each problem in turn.

The performance of the Iranian centrifuge now in operation at Natanz, called the IR-1, is not known although several estimates have been made. The Iranians have never formally published details of their centrifuges or the performance characteristics. The IAEA recognizes centrifuge separative capacity as legitimate proprietary data and does not collect it directly nor publish estimates. Nevertheless, some information can be gleaned from a wide range of sources. Estimates of IR-1 performance in the literature are based on some combination of (1) calculated performance based, in turn, on estimates of the physical characteristics of the machine, such as size and rotation speed obtained from sources or from author's estimates, (2) assumed analogs with known European machines that have imperfectly known performance or even less well known Pakistani machines, (3) unnamed sources of unascertainable credibility with supposed access to non-public data that cannot be verified, (4) calculated performance based on Iranian statements, primarily a television interview with Gholamreza Aqazadeh, the head of Iran's Atomic Energy Organization, or (5) data contained in IAEA reports.

In Table 1, prepared by FAS researcher Richard Abott, we show what we believe are the sources of the most commonly cited values for the IR-1. None of the sources as cited can be considered to have reliability that could be called scientific, such data are simply not publically available. The danger arises only when repeated citation makes us forget just how wobbly the foundations of our estimates really are.

The Aqazadeh interview is important. The interview, in Farsi but with English transcripts available, provides a surprising amount of quantitative data. Enough, in fact, to calculate the separative power of the IR-1. (There are a couple of apparent inconsistencies in the numbers but we believe these are easily resolved if references to flow in some cases refer to uranium and in other cases to uranium hexafluoride.) Calculation of the IR-1 performance based on this interview have been done by us (to be published soon) and others, including Richard Garwin.[2] While analysis of the Aqazadeh interview is significant, Garwin points out that the numbers are a useful measure of potential capacity and as a benchmark for comparison, writing, "...the above analysis shows how far from a nominal performance Iran's centrifuges must fall, to fail to produce HEU for nuclear weapons within a year after the action is taken to rearrange the plumbing..."

We suspect the result describes more closely what the Iranians *hope* to achieve with the IR-1 than what they actually achieve. (Of course, if strategic planning depends on worst case analysis, then Iranian potential performance might be more important than actual performance.)

The IAEA reports that, at least early on, "The throughput of the facility has been well below its declared design capacity."[3] There are a variety of reasons that the IR-1 might perform less well than calculation and analogy might suggest. Most citations of performance are actually references to the Pakistani P-1. That the IR-1 is basically a copy of the P-1 is fairly well established but the performance of the P-1 is estimated primarily by trying to find an analog with some better characterized European machine but there is not even a complete consensus on what that analog ought to be and the performance even of older European machines is not always available (centrifuge capacity is consider a proprietary and competition-sensitive value). Moreover, there is no guarantee that the Pakistanis, even with detailed technical data stolen by A. Q. Khan, were able to achieve the performance of the European models (the Pakistanis, not being parties to the Nonproliferation Treaty, are not subject to IAEA inspections so the outside world has almost no public information on the performance of the Pakistani machines). In addition, there is no guarantee that the Iranians were able to reproduce the performance of the Pakistanis machines even with their technical help. Thus, there are several links in the chain connecting half century old European technology to the IR-1 of today and we believe that knowledge of every link is uncertain.

Actual performance of the IR-1 may also fall short of expectation because, for example, more easily available, but weaker, rotor materials may have been substituted. Poor quality control in the manufacture of the rotors or bearings may cause a wide distribution of maximum sustainable speeds and, to keep the number of machine failures to tolerable levels, all the machines may be operated at lower speeds. Slight changes in rotor structure can change the flexural vibrational harmonics and reduce the critical frequency. Details of the design and manufacture of small components, for example, the product scoops, can have large effects on the efficiency of a machine.

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[2] Richard Garwin, "When could Iran deliver a nuclear weapon?" *Bulletin of the Atomic Scientists*, 17 January 2008, http://www.thebulletin.org/web-edition/features/when-could-iran-deliver-a-nuclear-weapon

[3] See § 43 of International Atomic Energy Agency Board of Governors, *Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions 1737 (2006) and 1747 (2007) in the Islamic Republic of Iran*, GOV/2008/4, 22 February 2008, http://www.iaea.org/Publications/Documents/Board/2008/gov2008-4.pdf

Table 1. Separative Power[4] of P-1 and *IR-1*[5] Centrifuges in Open Source Literature

Separative Power [kg-SWU/yr]	Source Year	Source Author	Source Name	Reference
1-3	2004	Gilinsky, *et al*	*A Fresh Examination of the Proliferation Dangers of Light Water Reactors*. Victor Gilinsky, Marvin Miller, Harmon Hubbard. October 22, 2004. The Nonproliferation Policy Education Center. P. 37&38.	"unclassified sources (and educated guesses)"
>1	2004	Boureston	"Fuel Cycle: Tracking the technology*,"* August 31 2004, Jack Boureston. *Nuclear Engineering International.*	"sources told Nuclear Fuel"
0.5-2	2005	Zentner	*Nuclear Proliferation Technology Trends Analysis*. M.D. Zentner, G.L. Coles, R.J. Talbert, September 2005. Pacific Northwest National Laboratory, PNNL-14480, p. 22	None. Urenco original model CNOR, SNOR numbers
1-2	2005	Zentner	*Nuclear Proliferation Technology Trends Analysis*. M.D. Zentner, G.L. Coles, R.J. Talbert, September 2005. Pacific Northwest National Laboratory, PNNL-14480, p. 22	None, Urenco original model G-1 numbers
2	2005	Glaser	*Life in a Nuclear Powered Crowd (The Problem of Uranium Enrichment),* Alexander Glaser, Program on Science and Global Security, Princeton University, New Approaches to Cooperative Security Workshop: Powerpoint presentation, slide 21.	None
3	2006	Albright & Hinderstein	*The Clock is Ticking, But How Fast?,* David Albright and Corey Hinderstein*, ISIS Report,* March 27, 2006.	"senior IAEA officials"
2.5-3	2006	Albright	"When Could Iran get the Bomb? What we know and what we don't know about Iran's nuclear program." David Albright*, Bulletin of the Atomic Scientists,* July/August 2006	None
2-3	2006	Lewis	"Collected Thoughts On Iranian LEU." *Arms Control Wonk,* Jeffrey Lewis. April 15, 2006.	Reverse engineer calculations from Steve Rademaker estimates.
1.4	2006	Albright	*Iran's Political/Nuclear Ambitions and U.S. Policy Options. A compilation of statements by witnesses before the Committee on Foreign Relations, 109th Congress, Second Session, May 17 & 18 2006.*	Based on calculations using Aqazadeh statement of 164-machine cascade

[4] In the literature, separative power is synonymously referred to as separative capacity, separative performance, or separative output.
[5] Specifically noted Iranian machines have SWUs in **bold**.

Separative Power [kg-SWU/yr]	Source Year	Source Author	Source Name	Reference
2.3	2006	Albright	*Iran's Political/Nuclear Ambitions and U.S. Policy Options. A compilation of statements by Witnesses before the Committee on Foreign Relations, 109th Congress, Second Session, May 17 & 18 2006.*	Based on calculations using Aqazadeh's public statements about Natanz' eventual 48,000 centrifuges
2.3	2006	Lewis	"More Fun With SWU," Jeffrey Lewis, *Arms Control Wonk,* April 18, 2006	own calculations from Aqazadeh statements
1.46	2006	Lewis	"Iranian Centrifuge Developments." Jeffrey Lewis, *Arms Control Wonk.* Friday, May 12, 2006.	commentor named "Richard Feynman" calculations
<1[6]	2007	Hibbs	*Pakistan developed more powerful centrifuges. Inside NRC*, A Platts.com Product and Services Highlight, Mark Hibbs, January 29, 2007.	"Western government intelligence"
2	2007	Albright	"A Witches' Brew? Evaluating Iran's Uranium-Enrichment Progress." David Albright and Jacqueline Shire. *Arms Control Today*. November, 2007	"level Pakistan is said to have achieved"
3	2007	Albright	"A Witches' Brew? Evaluating Iran's Uranium-Enrichment Progress." David Albright and Jacqueline Shire. *Arms Control Today*. November, 2007	"According to a former Urenco official…realistic maximum output"
about 2	2008	Albright & Shire	*Iran Installing More Advanced Centrifuges at Natanz Pilot Enrichment Plant: Factsheet on the P-2/IR-2 Centrifuge*, David Albright and Jacqueline Shire, ISIS, February 7, 2008	none
1.362	2008	Garwin	"When could Iran deliver a nuclear weapon?" Richard L. Garwin, *Bulletin of the Atomic Scientists*. January 17 2008	calculations based on Aqazadeh 2006 interview
2.5	2008	Lewis	*IR2 and IR3 Scoops,* ArmsControlWonk, May 27, 2008.	Scott Kemp calculations, based on 42% observed efficiency
2.5	2008	Jones	*Iran's Centrifuge Enrichment Program as a Source of Fissile Material for Nuclear Weapons*, Gregory S. Jones, April 8, 2008.	Albright & Hindernstein,*"*The Centrifuge Connection,*" Bulletin of Atomic Scientists,* March/April 2004 pp. 61-66
1-2[7]	2008	ISIS	*ISIS NuclearIran FAQ, What is a SWU?*	none
about 2.2	2009	Presbo	*Progress at Natanz (reposted). Verification, Implementation and Compliance (armscontrolverification.org),* February 27, 2009	None," based on a model with a separative factor of…"
2.1	2009	Salehi	*Iran Building New Generation of Centrifuges*. Fars News Agency, September 22, 2009.	Ali Akbar Salehi, head of the Atomic Energy Organization of Iran (AEOI)

[6] Individual segment on the P-1
[7] "Iran's P-1 centrifuges are estimated to have a maximum SWU of 3, and appear to be working at a level of between 1 and 2 SWU per year."

The centrifuges may not be operated at their most efficient throughput or the cuts (the ratio of product to feed) may not be optimal. Indeed, the IAEA reports indicate that the Iranians are not able to even *measure* their flow rates to within better than about a third,[8] making it highly unlikely that they are able to *optimize* their flow rates.

Estimates of the overall capability of Natanz are usually calculated by multiplying the enrichment performance of the IR-1 (which we have shown, we believe, to be highly uncertain) and the number of centrifuges (a number well established by IAEA inspection). But even if the performance of the machines were well established, such a simple calculation is inadequate; linking centrifuges together is more complex than that.

One centrifuge can process only a tiny fraction of the uranium needed by a nuclear power plant. Many machines are, therefore, operated in parallel to increase throughput. Such an arrangement is called a stage. Nor can one stage enrich uranium to fuel-grade level in one step, so the output of one stage provides the input for a next higher stage for further enrichment. Such an arrangement of stages is called a cascade. We have described cascades in detail elsewhere.[9]

The output of an ideal cascade is the output of a single machine multiplied by the number of machines but ideal output is never achieved in practice for a variety of reasons. Machines are never identical in operation so the output of the machines will not be the same yet all the outputs will be mixed, losing some separative work effort. The enriched output from one stage is passed up to the next higher stage for further enrichment. But, to conserve material, the waste, or relatively depleted output, from a stage is recycled back to a lower stage. Thus, each stage (except the bottom and top stages) has two input streams, from higher and lower stages (and the input stage, where natural uranium is fed into the cascade has three input streams). If these inputs are not perfectly balanced, material of different concentrations will be mixed and separative work already done will be wasted. When solving the equations for an ideal cascade, the number of centrifuges required in each stage will not necessarily be integer. The ideal cascade might contain a stage of, say, 5.4 centrifuges. Obviously, one cannot have 0.4 centrifuges so the stage will in fact contain either 5 or 6 machines and either the flow rates appropriate for the cascade will not be optimal for the machines or the optimal flow rates for the machines will not be optimal for the cascade.

Because of the complexity of linking centrifuges into cascades, the most common approach to estimating the capability of the Iranian facility should be modified. Rather than calculate a simple product by multiplying a highly uncertain machine capacity by the number of machines, that product should also be multiplied by an additional efficiency factor for the cascade, which we believe is also highly uncertain. The weakest aspect of this approach is that all of the uncertainties that create errors between estimated

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[8] Ivan Oelrich and Ivanka Barzashka, "Iran's Uranium: Don't Panic Yet." *FAS Strategic Security Blog*, 23 February 2009, http://www.fas.org/blog/ssp/2009/02/irans-uranium-dont-panic-yet.php
[9] Ivanka Barzashka and Ivan Oelrich, "Enrichment Cascades," http://www.fas.org/programs/ssp/nukes/fuelcycle/centrifuges/cascades.html

and actual performance point in the same direction, toward overestimating Iranian capacity.

We describe here the approach we used to produce the numbers we use in the *Bulletin* article describing the enrichment capacity of the newly discovered Fordow facility near Qom, which will reportedly use the same IR-1 machines that are currently being used in Natanz. We use well-documented, publicly available data from official IAEA reports and one assertion: **The best estimate of the near term capacity of the Fordow facility is the most recent capacity of the Nantanz facility, scaled by size.** We calculate the performance assuming a facility with 3000 centrifuges like those in Natanz (the IR-1) and a critical mass of enriched uranium of 25 kg. (Advanced bomb designs could definitely use less uranium; this is the IAEA "quantity of concern.")

Recent IAEA reports contain enough information to calculate the total enrichment capacity and efficiency of the entire Natanz facility, including the number of centrifuges in operation, the total throughput of the facility, the enrichment factors, and the amount of product.

Table 2 shows the key input parameters needed to calculate the Natanz capacity. The process quantities reported by the IAEA are for uranium hexafluoride; we prefer to work with quantities of uranium so those are listed also. (The molecular weight of uranium hexafluoride is 352 and of uranium 238 so one can convert from hexafluoride to uranium by multiplying by 238/352 or 0.676.)

We do make one correction to the feed. Since material is neither created nor destroyed and—we hope—not escaping into the environment, the total output should equal the total input. If fact, it does not because some material is held up in cold traps. (The rotors are spinning at very high speed so it is impossible to get a good seal between the rotor cap and the tubes running into the center of the rotor. Because of the strong radial g-forces toward the outside of the rotor, the density of material along the axis of the rotor is low and the leakage is small but there is nevertheless some leakage into the vacuum between the rotor and the outside container and the leaked material must be pumped out of that volume and sequestered in cold traps.) We assume that the material leaks out from each machine equally so the average U-235 concentration of the leaked material will equal the weighted average concentration of the material in the cascade, which should, in turn, equal the concentration of the feed material, which in this case in natural uranium.

Table 2. Iranian enrichment and throughput between 18 November 2008 and 30 October 2009.

Stream	UF6 (kg)	Uranium (kg)	% Conc
feed	**10412**	*7039*	*0.711*
hold up	**518**	*350*	*0.711*
effective feed		*6688*	**3.49**
product	**814**	*550*	
waste	**9080**	*6138*	*0.46*

Values in **bold** are taken from IAEA reports[10]; values in *italics* are calculated or assumed.

Eventually, the trapped material will be recovered and could be recycled. If the Iranians trapped material separately from each stage in the cascades, the material leaking from the enriching stages would be slightly enriched in U-235 and the material from the depleted, or stripping, stages would be depleted in U-235. They could then reintroduce the recovered material at the appropriate point in the cascade and salvage some of the invested separative work, in which case our estimates of facility capacity would have to be increases by a few, but never more than five, percent. We suspect the Iranian operation is not so sophisticated and most likely the recovered material will simply be reintroduced as feed and the separative work will be lost. If this is what the Iranians do, then it is reasonable simply use an *effective* feed rate, which would be equal to the actual feed minus the hold up and that is what we have done in these calculations.

The effectiveness of a centrifuge, cascade, or entire enrichment plant is described by the "separative work" it can do. The separative work is defined as the increase in the "value" of the material. The value function depends on the concentration of U-235 in the uranium and is defined in such a way that the work done by the centrifuge is independent of the concentration of the feed material. The value function, V, is a dimensionless quantity defined as:

$$V(x) = (2x-1)*\ln(x/(1-x))$$

where x is the relative concentration of U-235. The value of a certain amount of material at a certain concentration is simply the value function times the mass of the material. The separative work done by any enrichment process is the net increase in the value, that is

[10] Board of Governors, *Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions 1737 (2006), 1747 (2007), 1803 (2008) and 1835 (2008) in the Islamic Republic of Iran, IAEA Report GOV/2009/74*, 16 November 2009, http://www.iranwatch.org/international/IAEA/iaea-iranreport-111609.pdf

the difference between the value of the input and the combined values of the two output streams, one enriched, one depleted in U-235. That is,

ΔV = V(product)*Product Mass + V(waste)*Waste Mass - V(feed)*Feed Mass

Note that the quantities have units of mass so ΔV has the units of mass. ΔV is measured in mass "separative work units" or SWUs, typically kg-SWUs. The output of an entire enrichment plant is sometimes quoted in ton-SWUs. The amount of separative work performed in a certain amount of time is a separative power, typically kg-SWU/year. We have described elsewhere separative work and how it is calculated[11] and have developed a useful online separative work calculator.[12]

The IAEA report does not include a measurement of the waste concentration but that is easy to calculate, assuming that no U-235 is created or destroyed. The total amount of U-235 in the feed will show up in either the product or the waste. That is,

feed-235 = product-235 + waste-235

or

F*Cf = P*Cp + W*Cw

where F, P, and W are the masses and the Cs are the concentrations of U-235 in each. The concentration of the waste is simply

Cw = (F*Cf - P*Cp)/W.

All of the variables on the right hand side of the equation are given in the most recent IAEA report.

Table 3 shows the operating dates, quantities, concentrations, value functions, and total value for two cases. Based on the last physical inventory, the IAEA reported that up until November 2008, Iran was enriching its uranium to 3.49 percent and that is the first case. We also do a second case using a product concentration of 4.9 percent because elsewhere the IAEA reports that it has never detected any enriched material more concentrated than that. This serves as a worst case (in the sense that it provides a maximum estimate of capacity).

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11 http://www.fas.org/programs/ssp/nukes/effects/swu.html
12 http://www.fas.org/programs/ssp/nukes/nuclearcalculators/nuclear_cal.html

Table 3. Separative work of Natanz between 18 November 2008 and 30 October 2009

Stream	Concentration (%)	Value Function	Quantity (kg)	Total Value	Sep Work Kg-SWU
Feed	0.0071	4.8689	6688	32563.	
Product	3.49	3.0880	550	1698.	
Waste	0.46	5.3231	6138	32673.	1808
Product	4.9	2.6751	550	1471.	
Waste	0.34	5.6553	6138	34712.	3620

Note that between 18 November 2008 and 30 October 2009, the Natanz facility generated 1836 kg-SWUs assuming the lower product enrichment concentration and 3613 kg-SWUs using the higher concentration.

Now we need to develop a scaling factor, for which we will use an *effective* centrifuge capacity. Note that this may not be the actual centrifuge capacity. For example, the centrifuges may have significantly higher actual capacity but be inefficiently arranged in cascades, making the overall performance of the cascade low and the inferred performance of individual centrifuges would, therefore, appear low. We cannot say where inefficiencies appear and do not try to guess but using an effective centrifuge capacity allows an easy metric for comparison to other analyses.

To develop an effective centrifuge capacity, we need the total capacity divided by the number of centrifuges. Unfortunately, that number has been changing over time. Table 4 shows the number of centrifuges reported by the IAEA at various times during the period of interest. We make the simple approximation that the average number of centrifuges operating in the interval between two inspections is simply the arithmetic mean of the number at the beginning and the end of the interval. With this simple assumption, we are able to calculate the number of centrifuge-days for each interval and sum them for the entire period to arrive at a bit over one and a half million centrifuge-days. Next, we take the total separative work of the Natanz facility and divide by the total number of centrifuge-days and then multiply by 365 to convert to kg-SWU/year/centrifuge. The results are shown in Table 5.

Table 4. Centrifuge Machine-Days at Natanz

Period From	*Period To*	*Days Per Period*	*Average Number of Operating Machines*	*Machine-Days*
12-Aug-09	30-Oct-09	79	4264	336856
31-May-09	12-Aug-09	73	4756	347188
1-Feb-09	31-May-09	119	4428	526932
18-Nov-08	1-Feb-09	75	3854	289050
18-Nov-08	**30-Oct-09**	**346**		**1500026**

Table 5. Recent Effective Centrifuge Separative Capacity for Natanz, 1 November 2008 to 30 October 2009

Enrichment	*Separative Work*	*MachineDays*	*Separative Work/ Machine*	*Sep Work/ Machine*
%	*dU [kg SWU]*	*[days*no of machines]*	*[kg SWU/day/ cent]*	*[kg SWU/yr/ cent]*
3.49	1809	1500026	0.001205979	**0.44**
5.0	3620	1500026	0.002413292	**0.88**

The answer is 0.44 kg-SWU/year. This is the basis for the 0.5 kg-SWU/year that we used in our quick calculation in the *Bulletin* article and is about a quarter or fifth of the value typically used to estimate Iranian enrichment potential. If we take as a worst case that the total amount of enriched material has a U-235 concentration of 0.49 percent, a case that we consider highly unlikely, then the answer doubles to 0.88 kg-SWU/year.

The Fordow facility is reported to be set up for 3000 centrifuges (probably actually 2952, which is 18 of the 164 centrifuge cascades similar to those already operating in Natanz), which suggests a total facility capacity of 0.44*3000 or 1320 kg-SWU/year. Starting with natural uranium, producing an IAEA "quantity of concern" of 25 kilograms of 90 percent uranium for a primitive nuclear weapon (a more sophisticated design would use less uranium and a cautious estimate could use a smaller quantity although we caution that, if making consistent assumptions, we should be slow to assume a weapon design that requires a technical development that is radically more sophisticated than their demonstrated centrifuge capabilities), requires 5200 kg-SWU if the tails are a typical 0.25

percent, which implies that Fordow would take 3.9 years to produce enough 90 percent uranium for a bomb and this was the basis for our statement in the *Bulletin* that producing enough bomb-grade uranium would take "almost four years." The Iranians tend to set their waste assay higher than 0.25 percent. This reflects that uranium is cheaper to them than enrichment. If we assume a waste concentration of 0.4, a bit higher than currently produced at Natanz, then more uranium is required but only 4261 kg-SWUs, the equivalent of 3.2 years of Fordow production.

We believe, based on this analysis, that Iran's enrichment capacity is frequently seriously over represented. The data from the IAEA indicates that the Iranians have not yet become adept at enriching uranium.