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An In-Depth Examination of Iran's Centrifuge Enrichment Program and Its Efforts to Acquire Nuclear Weapons

Introduction

On June 2, 2011, my paper "Out of the Spotlight Iran's Rate of Enriched Uranium Production Continues to Increase: Centrifuge Enrichment and the IAEA May 24, 2011 Update" was posted on the Nonproliferation Policy Education Center website. I am the sole author of this paper. This was the fourteenth paper that I have written on Iran's nuclear program since early 2008.[2] (See Appendix 1) My prior thirteen papers generated some interest in the specialist community but little in the wider media. I had little expectation that media interest in the fourteenth paper would be any different from the media interest in my previous papers, but starting on June 6, 2011, there occurred a relative "explosion" of comments on the internet about my paper. Early comments about my paper contained several incorrect statements. As the comments multiplied, the misstatements tended to grow as well, since few commentators appeared to have actually read my paper and even fewer attempted to contact me. I posted some corrections to a few sites but as the comments became numerous, it became clear that attempting to do this site by site was a hopeless endeavor.

I have written this paper to respond to the numerous comments and misstatements that have been posted on the internet, as well as to provide an in-depth examination of Iran's centrifuge enrichment program and its efforts to acquire a nuclear weapons capability. This paper covers two areas. First, it discusses the origins of my June 2, 2011, paper and who has sponsored it. Second, it expands my analysis of Iran's centrifuge enrichment program, including my estimates for how long it would take for Iran to produce Highly Enriched Uranium (HEU) for nuclear weapons should it decide to do so; how these estimates compare with that of other experts and officials; why IAEA safeguards cannot prevent Iran from making nuclear weapons; how long it might take Iran to produce a nuclear weapon should it decide to proceed; whether Iran actually has a nuclear weapons program; when Iran might actually acquire nuclear weapons; and why Iran's possession of nuclear weapons matters. I have already presented much of this material in my previous papers, but it is consolidated here to provide a comprehensive analysis of these issues. A summary of the key points appears at the end of the paper.

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[1] The author has multiple affiliations. This paper was produced for the Nonproliferation Policy Education Center. Though the author is also a part-time adjunct staff member at the RAND Corporation, this paper is not related to any RAND project and RAND bears no responsibility for any of the analysis and views expressed in it.

[2] I also coauthored an article with Henry Sokolski, "Bombshell: Obama has run out of time to negotiate with Iran," *The New Republic*, December 7, 2010, http://www.tnr.com/article/79691/bombshell-iran-nuclear-bomb-uranium-negotiations-obama

The Origins of the June 2, 2011, Paper

In late 2007, I was approached by the Bipartisan Policy Center and the Nonproliferation Policy Education Center (NPEC) to provide an analysis of Iran's centrifuge enrichment program and how Iran might use this program to produce the HEU needed for nuclear weapons. The resulting paper was published on April 8, 2008, and was used as input to the Bipartisan Policy Center Report "Meeting the Challenge: U.S. Policy Toward Iranian Nuclear Development.[3]" In August 2009 the Bipartisan Policy Center commissioned me to produce an update of my prior work. This resulting paper was published August 17, 2009. I then added an appendix dated August 31, 2009 to update the paper in light of the IAEA safeguards report dated August 28, 2009. The paper of August 31, 2009, was used as input to the Bipartisan Policy Center Report "Meeting the Challenge: Time Is Running Out" dated September 15, 2009.

I had thought that this would be the end of my work on Iran but in October 2009, there was a proposal for Iran to ship a significant portion of its stockpile of 3.5% enriched uranium out of the country. In turn, Iran would be provided with a large stock of 19.75% enriched uranium in the form of research reactor fuel. Much of the discussion on this proposal contained serious technical errors and also ignored the risks of providing Iran with uranium enriched to such a high level, even if it was in the form of research reactor fuel. Therefore on October 12, 2009, I published a paper on the NPEC website to address these issues.

Thereafter, I published an additional eleven papers on the NPEC website. Seven of these papers (including the paper published on June 2, 2011) were further updates on Iran's enrichment progress, based on the quarterly IAEA safeguard updates on Iran. The other four addressed additional issues related to Iran's possible acquisition of nuclear weapons. These issues were: statements by U.S. government officials as to how long it might take Iran to produce a nuclear weapon; statements by former Israeli government officials as to how long it might take Iran to produce a nuclear weapon; the false belief that cyber attacks have slowed Iran's uranium enrichment; and a critique of a report by the International Institute for Strategic Studies (IISS) on their estimates of how long it would take Iran to produce HEU and a nuclear weapon.

It is important to note that though I was-and remain-a consultant to the RAND Corporation (an adjunct staff member) none of this work was performed for RAND. Statements referring to me as a RAND research staff member, while strictly accurate, are misleading in the context of my June 2, 2011, paper since they falsely imply that the work was performed as part of my RAND duties. RAND issued a press release to clarify the issue.

My NPEC paper was released about the same time as a RAND report on Iran which was published on June 7, 2011.[4] The timing of my paper relative to that of the RAND report

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[3] The report was published on September 19, 2008. My paper provided input to that report but I was not an author of that report.
[4] Lynn E. Davis et al., "Iran's Nuclear Future: Critical U.S. Policy Choices," RAND, 2011.

was purely coincidental. I had no role in the RAND report. The timing of my paper was driven by the May 24, 2011 release of the IAEA's safeguards report on Iran. Such reports are released roughly quarterly by the IAEA, and indeed I published a similar paper exactly one year earlier on June 2, 2010.

Having gone through these preliminaries, I will now address the far more important matter of how Iran's centrifuge enrichment program could be used to produce HEU for nuclear weapons and how Iran is taking steps to acquire nuclear weapons.

IRAN'S CENTRIFUGE ENRICHMENT PROGRAM AND NUCLEAR WEAPONS

Information Provided by the IAEA

In the past, when analysts have evaluated various countries' nuclear programs and addressed the issue of how they might be used to provide fissile material for nuclear weapons, often little specific technical information was available. As a result, calculations would have to be parametric in nature, with reasonable assumptions used to provide a range of possible fissile material production rates. The situation for Iran is quite different. Since Iran is subject to IAEA safeguards and since the IAEA publishes the results of its inspections, much more technical information about Iran's centrifuge enrichment program is available so that far more detailed calculations of fissile material production rates are possible.[5]

Iran has three known centrifuge enrichment facilities. Iran's main facility is the Fuel Enrichment Plant (FEP) at Natanz. The basic unit of Iran's centrifuge enrichment effort is a cascade which consists of 164 centrifuges, though Iran has begun to modify some cascades by increasing the number of centrifuges to 174. All centrifuges installed up to now have been of the IR-1 type. Each cascade is designed to enrich natural uranium to 3.5% enriched uranium. As of May 14, 2011, Iran had installed 53 cascades containing approximately 8,000 centrifuges at the FEP. Of these 53 cascades, only 35 (containing 5,860 centrifuges) were being fed with uranium hexafluoride and therefore producing 3.5% enriched uranium.[6]

Also at Natanz, Iran has the Pilot Fuel Enrichment Plant (PFEP) which is used to test a number of more advanced centrifuge designs. These are usually configured as single centrifuges or small ten or twenty centrifuge test cascades. However, Iran has indicated that it plans to install two full cascades containing more advanced centrifuges (one cascade using IR-4 centrifuges and one cascade using IR-2m centrifuges) which could significantly increase the rate of Iran's production of 3.5% enriched uranium. In addition, there are two full cascades each with 164 IR-1 type centrifuges at the PFEP. These two cascades are interconnected and are being used to process 3.5% enriched uranium into 19.7% enriched uranium.

Finally Iran is constructing an enrichment facility near Qom. Known as the Fordow Fuel Enrichment Plant (FFEP), this plant's construction was started clandestinely in violation of its IAEA safeguards. Its existence was only revealed by Iran in September 2009 after Iran believed that the plant had been discovered by the West. No centrifuges have yet been installed at FFEP.

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[5] The most recent such report is: *Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions in the Islamic Republic of Iran*, GOV/2011/29, May 24, 2011.

[6] The IAEA's description of the number of centrifuges being fed with uranium hexafluoride is rather ambiguous: "The 35 cascades being fed with UF_6 on that date contained a total of 5860 centrifuges, some of which were possibly not being fed with UF_6." *Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions in the Islamic Republic of Iran*, GOV/2011/29, May 24, 2011, p.2.

Iran has been producing 3.5% enriched uranium at the FEP since February 2007. As of May 14, 2011 it had produced a total of 2,775 kilograms (in the form of 4,105 kilograms of uranium hexafluoride[7]). Based on the IAEA's safeguards reports, I have calculated the average Iranian monthly production rate of 3.5% enriched uranium starting from near the end of 2008. The results are shown in Table 1. As can be seen, while being steady at around 55 kilograms per month for much of 2009, the production rate has now almost doubled to around 105 kilograms per month.

Table 1
Average Iranian Production Rate of 3.5% Enriched Uranium
Late 2008 to Mid-2010

IAEA Reporting Interval	Average 3.5% Enriched Uranium Production Rate (Kilograms Uranium per Month)
11/17/08-1/31/09	52
2/1/09-5/31/09	53
6/1/09-7/31/09	57
8/1/09-10/31/09	57
11/22/09-1/29/10	78
1/30/10-5/1/10	81
5/2/10-8/6/10	80
8/7/10-10/17/10	95
10/18/10-2/5/11	88
2/6/11-5/14/11	105

Iran began producing 19.7% enriched uranium at the PFEP in February 2010. Since production began, the rate of 19.7% enriched uranium production has been fairly steady and as of the last IAEA safeguards report, the rate was 2.6 kilograms per month. As of May 21, 2011, Iran had accumulated about 38.3 kilograms of 19.7% enriched uranium (in the form of 56.7 kilograms of uranium hexafluoride). As of the May 21, 2011, date, about 320 kilograms of 3.5% enriched uranium would have been processed into 19.7% enriched uranium, leaving Iran with about 2,455 kilograms of 3.5% enriched uranium. Though Iran claims that it is producing this enriched uranium for peaceful uses, all of the 3.5% enriched uranium and the 19.7% enriched uranium is just being stockpiled.

From the Iranian production rate of 105 kilograms per month of 3.5% enriched uranium at the FEP, it can be easily calculated that this plant's current enrichment production

[7] The IAEA reports Iran's enriched uranium production in terms of uranium hexafluoride. However, since the production of nuclear weapons involves the use of metallic uranium, we report the uranium content of the uranium hexafluoride, which can be found by multiplying by 0.676. Note that the failure to make this distinction can lead to confusion since the IAEA's uranium hexafluoride figures are sometimes erroneously reported as uranium alone.

capacity is about 4,600 separative work units (SWU, see Appendix 2) per year.[8] Given that in the past Iran's centrifuges were each producing about 0.89 SWU per year, 4,600 SWU per year would indicate that the equivalent of about 31 cascades (5,184 centrifuges) were in operation. Note that Iran had 31 cascades in operation at the end of the last IAEA reporting period on February 20, 2011. Since the IAEA has indicated that on May 14, 2011, Iran had 35 cascades producing 3.5% enriched uranium, this implies that either some cascades are not operating at full effectiveness or that the new cascades only came online near the end of the current IAEA reporting period. In any event, what is important is Iran's current enrichment capacity (4,600 SWU per year) and not the exact number of centrifuges Iran has in operation.

How Could Iran Produce the HEU Required for a Nuclear Weapon?

Iran's stockpiles of 3.5% and 19.7% enriched uranium, its enrichment capacity of 4,600 SWU at the FEP, it ability to manufacture new centrifuges as well as its ability to transfer centrifuges from one facility to the other, all give Iran a number of options for producing the 20 kilograms of HEU required for a nuclear weapon.[9] Two distinct possibilities involve either Iran using its existing enrichment facility at the FEP or Iran using a specially constructed clandestine enrichment facility. We will examine each possibility in turn.

Using the FEP to produce enriched uranium

It has long been known that the technical properties of centrifuges allow for the fairly easy production of HEU from a centrifuge enrichment facility even if the facility was not designed to produce HEU. Writing as long ago as 1979 with my colleagues Albert and Roberta Wohlstetter, we said: "Our analysis of enrichment technologies so far has focused on the current or near-term state of the art. It shows that the transfers of some current technologies, and in particular the centrifuge, need to be restricted if highly enriched uranium for bombs is not to become easily accessible to many nonweapon states."[10]

A 1988 training course for the IAEA, conducted by Martin Marietta Energy Systems (which at that time was operating the Oak Ridge enrichment plant for the U.S. Department of Energy) confirms this point: "…there are several characteristics of the gas centrifuge enrichment process that enable a centrifuge facility designed for produce LEU [low enriched uranium, i.e. uranium enriched to 3% to 5%] to be used for the undeclared production of HEU. Specifically, these features include a high separation factor, a small

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[8] Assuming 0.4% tails.

[9] Iran's stockpiles of enriched uranium are important since, in separative work terms, 3.5% enriched uranium is over 60% of the way to 90% enriched uranium and 19.7% enriched uranium is about 90% of the way to 90% enriched uranium.

[10] Albert Wohlstetter, Gregory Jones, Roberta Wohlstetter, "Why the Rules Have Needed Changing", *Towards a New Consensus on Nuclear Technology*, Volume I, PH-78-04-832-33, Pan Heuristics, Prepared for U.S. Arms Control and Disarmament Agency, July 6, 1979, p.73. http://www.npolicy.org/files/19790706-TowardsANewConsensus-Vol01.pdf

in-process inventory, and a short equilibrium time."[11] The course materials also state that the production of HEU can be carried out either by "batch recycling operations" or by "reconfiguring the process piping."[12] These processes are discussed below.

Batch Recycling

According to Martin Marietta, "In batch recycle, the approach involves recycling cascade product on a batch basis using one or more unit cascades. In this method, physical modifications to the process and support systems are not necessarily required to produce HEU successfully."[13] "...batch recycling is a viable option for a small centrifuge facility. Reflux and criticality problems do not arise in the cascade because of the use of low-pressure UF_6 gas. However, precautions must be taken in product-collecting areas where the gas is returned to the solid phase."[14] In other words, due to the higher enrichment of the product in batch recycling, criticality safe containers must be used when the gas is converted back to a solid.

Batch recycling is the process of greatest concern since it allows Iran to produce the HEU needed for a nuclear weapon in the least amount of time. Iran's cascades at the FEP produce 3.5% enriched uranium from natural uranium (usually considered to have an enrichment of 0.711%). Without modification these cascades could produce HEU in a three step process, starting from 3.5% enriched uranium. In the first step, 15.5% enriched uranium would be produced from 3.5% enriched uranium, in the second step, 48.2% enriched uranium would be produced from the 15.5% enriched uranium and in the third step 82.5% enriched uranium would be produced from the 48.2% enriched uranium.[15]

But a simple modification to the cascades can improve this process. As Martin Marietta points out, it is possible to increase the enrichment in each step by reducing the flow through the cascade.[16] As long as the flow is not reduced too severely, the separative capacity is not greatly reduced. It is not possible to use this method alone to produce 90% enriched uranium from 3.5% enriched uranium but Glaser has shown that reduced cascade flow can be used to improve the batch recycling process by reducing the number of cycles from three to two.[17] In the two step process, the first step would produce 19.7% enriched uranium from 3.5% enriched uranium and then the second step would take the

[11] "Safeguards Training Course: Nuclear Material Safeguards for Enrichment Plants, Part 4. Gas Centrifuge Enrichment Plant: Diversion Scenarios and IAEA Safeguards Activities", K/ITP--156/P4/R1, Martin Marietta Energy Systems, Inc., Oak Ridge, Tennessee, October 1988, p.148.
[12] *Ibid.*, p.187.
[13] *Ibid.*, p.178.
[14] *Ibid.*, p.148.
[15] Though weapon states have generally used HEU with an enrichment of at least 90%, it is known that HEU with an enrichment of at least 80% can be used for nuclear weapons. For example, the first South African nuclear weapon used HEU with an enrichment of 80%. See: David Albright, "South Africa and the Affordable Bomb", *Bulletin of the Atomic Scientists*, July/August 1994, pp.37-47.
[16] "Safeguards Training Course: Nuclear Material Safeguards for Enrichment Plants, Part 4. Gas Centrifuge Enrichment Plant: Diversion Scenarios and IAEA Safeguards Activities", K/ITP--156/P4/R1, Martin Marietta Energy Systems, Inc., Oak Ridge, Tennessee, October 1988, p.165.
[17] Alexander Glaser, "Characteristics of the Gas Centrifuge for Uranium Enrichment and Their Relevance for Nuclear Weapon Proliferation", *Science and Global Security*, Vol. 16, 2008, p.16.

19.7% enriched uranium and further enrich it to the 90% level for use in a nuclear weapon.[18] I have performed calculations based on the two-step process, taking into account Iran's current stockpile of 19.7% enriched uranium. The results are shown in Table 2.

Table 2

Time, Product and Feed Requirements for the Production of 20 kg of HEU by Batch Recycling at the FEP (4,600 SWU per year, 31 Equivalent Operating Cascades, 5,184 Centrifuges, 0.89 SWU per Centrifuge-Year)

Cycle	Product Enrichment and Quantity	Feed Enrichment and Quantity	Time for Cycle (Days)
First	19.7% 119.9 kg	3.5% 1,415 kg	46
Second	90.0% 20 kg	19.7% 153.2 kg*	12
Total			62**

* Includes 38.3 kilograms of 19.7% enriched uranium that Iran has already stockpiled.
**Includes four days to account for equilibrium and cascade fill time.

As can be seen, Iran can now produce the 20 kilograms of HEU needed for a nuclear weapon in about two months should it decide to do so. Most of this time is taken by the first step, where 3.5% enriched uranium is enriched to 19.7% enriched uranium. This first step in this batch recycling process is more than a theoretical possibility, since Iran is already producing 19.7% enriched uranium from 3.5% enriched uranium. Iran used one of its standard 164 centrifuge cascades to start this process. Since as was stated above, if the flow through the cascade were unaltered, only 15.5% enriched uranium would be produced, it is apparent that Iran has reduced the flow though the cascade, so that 19.7% enriched uranium is being produced instead.

Also, since Iran has already established the principle that it can enrich 3.5% enriched uranium to 19.7% enriched uranium, it is not clear that the first step in the batch recycle process would be considered a safeguards violation. Only the second step of batch recycling might be considered a violation of safeguards but by then Iran would need only about two weeks to produce the HEU required for a nuclear weapon.

That Iran can produce the 20 kilograms of HEU required for a nuclear weapon in just two months is a dramatic reduction in the time that would have been required only a few years ago. In the first part of 2008 when I made my first calculations, I estimated that it

[18] In his analysis, Glaser also uses two steps. In his first step, 3.5% enriched uranium is enriched to 16.3% and then in his second step the 16.3% enriched uranium is enriched to 91.0%. While obviously differing in detail, the principle is the same.

would take Iran two to four years to be able to produce the HEU required for a nuclear weapon.

Further, as Iran's stockpile of 19.7% enriched uranium continues to grow, the time required for Iran to produce HEU will continue to decline. When Iran has a stockpile of about 160 kilograms of 19.7% enriched uranium, it will be possible to skip the first step entirely and Iran will be able to produce 20 kilograms of HEU in only about 2 weeks. At Iran's current rate of production of 19.7% enriched uranium, the time when Iran will have a stockpile of 160 kilograms of 19.7% enriched uranium is still about four years away. However, Iran has recently announced that it plans to triple its rate of production of 19.7% enriched uranium.[19] Not everything that Iran has been announced about its enrichment program has come to pass but if Iran can carry through on this proposal reasonably soon, then it might have the required 160 kilograms of 19.7% enriched uranium by the end of 2012.

One disadvantage of the batch recycling process is that it requires relatively large amounts of 3.5% enriched uranium to produce the required 20 kilograms of HEU needed for a nuclear weapon. Starting from 3.5% enriched uranium and having no intermediate stockpile of 19.7% enriched uranium, it takes about 1,900 kilograms of 3.5% enriched uranium to produce 20 kilograms of 90% enriched uranium by batch recycling. In contrast, if one uses an enrichment plant designed specifically to produce 90% enriched uranium from 3.5% enriched uranium, then it would only take about 600 kilograms of 3.5% enriched uranium to produce 20 kilograms of 90% enriched uranium. The reason for this difference is that the tails in the latter case would be only 0.4% enriched uranium meaning that most of the U-235 contained in the 3.5% enriched uranium would end up in the 90% enriched product. However, in the first batch recycle step the tails are 2.0% enriched uranium and in the second step 9.2% enriched uranium, so that much of the U-235 in the original 3.5% enriched uranium is "lost" to the tails. In reality, Iran could eventually extract the U-235 from these tails but in the short term 1,900 kilograms of 3.5% enriched uranium would be needed to produce the required 20 kilograms of 90% enriched uranium.

With Iran's current setup it can produce 20 kilograms of HEU from somewhat less than 1,900 kilograms of 3.5% enriched uranium. In February 2010 Iran started producing 19.7% enriched uranium from 3.5% enriched uranium using one of its standard 164 centrifuge cascades. As stated above the tails from this process would have had an enrichment of 2.0%. To utilize its 3.5% enriched uranium more efficiently, in July 2010 it added a second of its standard 164 centrifuge cascades to this process but rather than increase its output of 19.7% enriched uranium, this second cascade was used to reduce the tails enrichment from 2.0% to 0.7%. This reduction increases the amount of 19.7% enriched uranium that can be produced from a given amount of 3.5% enriched uranium by about 73%. The effect of this improvement can be seen from Table 2. Currently it would take about 1415 kilograms of 3.5% enriched uranium when used with Iran's existing stockpile of 38.3 kilograms of 19.7% enriched uranium to produce 20 kilograms

[19] David E. Sanger and William J. Broad, "Iran Says It Will Speed Up Uranium Enrichment", *New York Times*, June 8, 2011.

of HEU. Since it took about 320 kilograms of 3.5% enriched uranium to produce the 38.3 kilograms of 19.7% enriched uranium, this means that Iran could produce 20 kilograms of 90% enriched uranium from about 1,735 kilograms of 3.5% enriched uranium. Since Iran has already produced 2,775 kilograms of 3.5% enriched uranium it has more than enough to produce this much HEU.

Further as noted above, if Iran wanted to produce a second 20 kilogram batch of 90% enriched uranium (so that it would have a total of 40 kilograms, enough for two nuclear weapons), then it would require 1,900 kilograms of 3.5% enriched uranium. Added to the 1,735 kilograms required for the first 20 kilogram batch of 90% enriched uranium, Iran would need to produce just over 3,600 kilograms of 3.5% enriched uranium in total. Given that Iran has already produced 2,775 kilograms of 3.5% enrich uranium and is producing about 105 kilograms, by the beginning of next year Iran will be in a position to produce two nuclear weapons worth of HEU. Table 3 shows how this process would be carried out.

Since Iran would have already consumed its stockpile of 19.7% enriched uranium by producing the first batch of 20 kilograms of HEU, this case would take about two and one half months. The production of the HEU for two weapons would have to be carried out sequentially with the production of the HEU for the first weapon taking about two months (Table 2) and the production of the HEU for the second weapon taking about two and one half months (Table 3) for a total of about four and one half months. These times should be considered the maximum since by the beginning of 2012, Iran will have produced more 19.7% enriched uranium and likely will have added even more enrichment capacity which will shorten the time required.

Table 3

Time, Product and Feed Requirements for the Production of a Second Batch of 20 kg of HEU by Batch Recycling at the FEP (4,600 SWU per year, 31 Equivalent Operating Cascades, 5,184 Centrifuges, 0.89 SWU per Centrifuge-Year)

Cycle	Product Enrichment and Quantity	Feed Enrichment and Quantity	Time for Cycle (Days)
First	19.7% 158.2 kg	3.5% 1,872 kg	61
Second	90.0% 20 kg	19.7% 153.2 kg	12
Total			77*

*Includes four days to account for equilibrium and cascade fill time.

Reconfiguring the Process Piping

Iran's centrifuge enrichment plant at the FEP consists of over 30 cascades operating in parallel, each producing 3.5% enriched uranium from natural uranium. It would be possible to repipe the enrichment plant, so that the cascades operated in series and thereby produce the 90% enriched uranium needed for a nuclear weapon. The amount of time needed to repipe the FEP is unknown. To produce an accurate estimate, one would have to be a centrifuge enrichment plant engineer and know the design details of the FEP. Various analysts have produced guesstimates of the time require, which are usually several months. For example, the IISS has estimated that repiping the FEP would take a minimum of three months.[20]

One way that the FEP could be repiped would be to create a cascade that could produce HEU starting from natural uranium. Glaser has illustrated how this could be carried out.[21] It would take the repiped enrichment plant about nine months to produce the 20 kilograms of HEU needed for a nuclear weapon.[22] Adding the minimum of three months required to repipe the FEP, this process would require at least one year, which is far longer than the 2 months required by the batch recycle process. One of the reasons it takes the repiped FEP so long to produce HEU is that it produces HEU from natural uranium, and does not take advantage of Iran's sizable stockpiles of 3.5% and 19.7% enriched uranium.

In order to produce the HEU more quickly, some have suggested that the FEP be repiped so as to produce HEU starting with 3.5% enriched uranium. This allows Iran to utilize its stockpile of 3.5% enriched uranium but not its stockpile of 19.7% enriched uranium. If repiped in this way, the FEP could produce the 20 kilograms of HEU needed for a nuclear weapon in about three months.[23] Adding the minimum of three months needed to repipe the FEP, the HEU would be produced in at best six months. While this is significantly shorter than the one year required for the repiped FEP which produces HEU from natural uranium, it is still much longer than if the HEU were produced by batch recycle.

One problem with repiping the FEP to produce HEU from 3.5% enriched uranium is that the plant could only operate as long as Iran's stockpile of 3.5% enriched uranium lasted. Iran's current stockpile of 3.5% enriched uranium (2,455 kilograms) would run out after Iran had produced 77 kilograms of HEU which would be enough for about four nuclear weapons. It would take about one year to process all of the 3.5% enriched uranium into HEU. Adding in the minimum of three months needed to repipe the plant, a total time of approximately 15 months would be required. Once the stockpile of 3.5% enriched

[20] *Iran's Nuclear, Chemical and Biological Capabilities, A net assessment*, an IISS strategic dossier, The International Institute for Strategic Studies, London, 2011.
[21] Alexander Glaser, "Characteristics of the Gas Centrifuge for Uranium Enrichment and Their Relevance for Nuclear Weapon Proliferation", *Science and Global Security*, Vol. 16, 2008, pp.17-19.
[22] 0.4% tails.
[23] 0.711% tails, i.e., the enrichment equal to that of natural uranium.

uranium has been exhausted, the FEP would need to be repiped a second time so as to be able to produce additional HEU from natural uranium.

Repiping the FEP or using batch recycle at the FEP are not mutually exclusive. The best strategy for Iran would be to use batch recycle at the FEP to produce one or two weapons relatively quickly. As was shown in the last section, Iran could currently produce the HEU for a nuclear weapon in just two months. Once it has accumulated a large enough stockpile of 3.5% enriched uranium which will probably occur by the beginning of 2012, it could produce enough HEU for a second nuclear weapon in an additional two and one half months. Once Iran had exhausted its stockpiles of enriched uranium, it could then repipe the FEP and use it for sustained HEU production using natural uranium as feed.

Producing HEU in a Clandestine Enrichment Facility

Since Iran can produce its own centrifuges and also can transfer centrifuges from safeguarded facilities to unknown locations (IAEA safeguards do not apply to the centrifuges once they leave a safeguarded facility), Iran has the option to produce HEU at a clandestine enrichment plant. Since Iran continues to refuse to implement the Additional Protocol to its safeguards agreement, the IAEA would find it very difficult to locate a clandestine enrichment plant—a fact that the IAEA has continued to confirm.[24] While this has been a theoretical possibility since 2007, its salience increased with the discovery in September 2009 that Iran was actually building such a clandestine enrichment plant (the FFEP near Qom).

A clandestine enrichment plant containing 23 cascades (3,772 centrifuges, 0.89 SWU per centrifuge-year) could produce around 20 kilograms of HEU (the amount required for a nuclear weapon) each year using natural uranium as feed. Since this option does not require any overt breakout from safeguards, the relatively slow rate of HEU production would not necessarily be of any concern to Iran. Such production could be going on right now and the West might well not know. A clandestine enrichment plant would need a source of uranium but Iran is producing uranium at a mine near Bandar Abbas.[25] Since Iran has refused to implement the Additional Protocol to its IAEA safeguards, this uranium mining is unsafeguarded and the whereabouts of the uranium that Iran has produced there is unknown.

A clandestine 23 cascade enrichment plant could also be used to convert Iran's stockpile of 3.5% enriched uranium into the HEU required for weapons. The 20 kilograms of HEU

[24] "While the Agency continues to verify the non-diversion of declared nuclear material at the nuclear facilities and LOFs declared by Iran under its Safeguards Agreement, as Iran is not providing the necessary cooperation, including by not implementing its Additional Protocol, the Agency is unable to provide credible assurance about the absence of undeclared nuclear material and activities in Iran, and therefore to conclude that all nuclear material in Iran is in peaceful activities." *Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions in the Islamic Republic of Iran*, GOV/2011/29, May 24, 2011, p.9.

[25] *Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions in the Islamic Republic of Iran*, GOV/2011/7, February 25, 2011, p.9.

needed for a weapon could be produced in about four and one-half months.[26] Further only about 600 kilograms of 3.5% would be required to produce 20 kilograms of HEU, so the current stockpile of about 2,450 kilograms of 3.5% enriched uranium would be more than enough for four weapon's worth of HEU, though this entire process would take more than one year to complete. However, using its current stockpile in this fashion would require Iran to violate IAEA safeguards, which would expose Iran to Western counteraction over these four and one half months. The time required could be shortened by assuming that the clandestine enrichment plant contains more that 23 cascades but a very large clandestine enrichment plant appears to be implausible currently, given Iran's resources. As a result, it is more likely that if Iran were to use the clandestine enrichment route, it would use a plant that used natural uranium as feed since there would then be no need to overtly violate safeguards.

Comparison with Other Estimates

How do these estimates of the time it would take Iran to produce enough HEU for a nuclear weapon compare to those of other analysts? As we will see, when the same assumptions are used, the estimates are generally quite similar.

In 2006 Kemp and Glaser presented a general analysis of the ease with which gas centrifuge technology could be used to produce HEU.[27] This paper had no particular focus on Iran. They said that "The gas centrifuge is a particularly challenging technology for the institutions of the existing nonproliferation regime." They calculated that if a stockpile of 4.4% enriched uranium were to be batch recycled in an enrichment facility with a separative capacity of 55,000 SWU per year (significantly larger than Iran's current 4,600 SWU per year) then 25 kilograms of HEU could be produced in less than two weeks. They went on to say "…this breakout scheme is simple and fast to implement and minimizes the risk of timely detection and thus international response."

In March 2009 Kemp and Glaser provided an analysis of Iran's centrifuge enrichment program.[28] They assumed that Iran's goal would be to produce 25 kilograms of HEU for a nuclear weapon. They calculated that Iran would need a stockpile of 2,200 kilograms of 3.5% enriched uranium to batch recycle at Natanz in order to produce this much HEU. Since as of February 2009 Iran had produced only 683 kilograms of 3.5% enriched uranium, they estimated that depending on Iran's future rate of 3.5% enriched uranium production, it would take Iran somewhere between six and 31 months for Iran to acquire this much 3.5% enriched uranium.[29] Kemp and Glaser stated that once Iran had this stockpile it would be in a position to be able to batch recycle the 3.5% enriched uranium at the FEP to produce the 25 kilograms of HEU. They calculated that depending on the

[26] Using tails of 0.4%.
[27] R. Scott Kemp and Alexander Glaser, "The Gas Centrifuge and the Nonproliferation of Nuclear Weapons," *Proceedings of the Ninth International Workshop on Separation Phenomena in Liquids and Gases (SPLG)*, September 18-21, 2006, Beijing, China, Tshinghua University Press, 2007, pp. 88-95.
[28] R. Scott Kemp, and Alexander Glaser, "Statement on Iran's ability to make a nuclear weapon and the significance of the 19 February 2009 IAEA report on Iran's uranium-enrichment program," March 2, 2009. http://www.princeton.edu/~rskemp/can-iran-make-a-bomb.pdf
[29] Iran achieved this stockpile size in about 19 months (November 2010).

separative capacity at the FEP, this batch recycle process could take between seven weeks and six months.

If Kemp and Glaser had taken as Iran's goal the production of 20 kilograms of HEU (the goal I use in my calculations), then their requirement for the size of Iran's 3.5% enriched uranium stockpile would have been reduced to about 1,800 kilograms, which is close to my calculation of 1,900 kilograms. Given the current separative capacity at the FEP (4,600 SWU per year) and again taking the goal of the production of 20 kilograms of HEU, Kemp's and Glaser's estimate would be 12 weeks. Since at that time, Kemp and Glaser did not know that Iran would also have a stockpile of 19.7% enriched uranium (Iran did not start producing this material until February 2010), the proper comparison is with my Table 3, which indicates a time of 11 weeks. This is very close to the 12 week period they would have calculated and thus Kemp's and Glaser's calculations and mine yield very similar results.[30]

The International Institute for Strategic Studies (IISS) published an estimate in February 2011 which stated that it would take Iran between 6 and 17 months to produce the HEU needed for a nuclear weapon and its preferred estimate was 17 months.[31] I have critiqued this work in detail elsewhere but I will highlight the main differences which all have to do with differences in input assumptions.[32]

The IISS's preferred estimate of 17 months assumes that Iran would take the longer path of repiping the FEP rather than the significantly shorter path of using batch recycle. Its estimate for the production of HEU at the FEP by batch recycling is only 6 months. The IISS calculations assume that the separative capacity at the FEP is only about 3,500 SWU per year which was appropriate for the first half of 2010 but not for 2011 when the separative capacity is 4,600 SWU per year. Using the higher separative capacity would reduce the IISS's estimate from 6 months to only about 4.5 months. The IISS assumes that Iran would have to produce 37.5 kilograms of HEU for a single weapon, arguing that there would be significant wastage in the production of the HEU metal sphere required for a nuclear weapon. They calculated this number by starting from the IAEA's "significant quantity" of 25 kilograms of HEU and multiplying by 1.5. This however, ignores the fact that the IAEA's significant quantity already includes a wastage factor as well as the fact that since HEU is more valuable than gold, any material "lost" in processing would be recovered and reused. If the IISS's estimate used a goal of 20

[30] Kemp obtained his PhD in 2010 and he now works for the U.S. State Department, which has ended his collaboration (and publications on Iran's enrichment program) with Glaser.

[31] They also assumed that an additional six months would be required to produce an actual weapon, making their total estimate between one and two years with their preferred estimate being two years. However, this estimate makes the mistake of assuming that the production of HEU by Iran and the development of a nuclear weapon by Iran would have to take place in sequence when in fact it could take place in parallel. This will be discussed in more detail below.

[32] Gregory S. Jones, "Critique of IISS Estimates of the Time Required for Iran to Produce the HEU Metal Core Required for a Nuclear Weapon, Addendum: Time Required to Produce the Non-Nuclear Components Needed for a Nuclear Weapon," March 3, 2011, Revised April 6, 2011 http://www.npolicy.org/article_file/Critique_of_IISS_Estimates_with_Addendum.pdf

kilograms instead of 37.5 kilograms then its estimate would drop to only about 2.5 months which is close to my estimate and to Kemp's and Glaser's estimate.

Other estimates of when Iran might be able to produce the HEU required for nuclear weapons are often given as flat statements with no supporting analysis. This is especially so for the estimates given by various U.S. government officials. In many cases these estimates appear to be merely wishful thinking. As I have written elsewhere, the distinguished intelligence analyst Roberta Wohlstetter noted a phenomenon where analysts when faced with an unpleasant reality instead engage in self-deception by constructing a more pleasant fiction that allows the analysts to avoid facing up to the more unpleasant reality.[33]

One example that falls into this category was Iran's supposed problem with molybdenum contaminating its uranium supplies.[34] An unnamed U.S. State Department official claimed that Iran's uranium was "tainted with large amounts of molybdenum and other heavy metal." "An IAEA specialist said that the impurities "might condense and thereby risk blockages of valves and piping" [in Iran's enrichment plant]. The upshot of this supposed problem was that Iran's enrichment program would be delayed which would buy the West "months" that would allow time for diplomacy to stop it. This story circulated in the early part of 2006. In retrospect, molybdenum was clearly not a major problem for Iran which has since produced a sizable stockpile of 3.5% enriched uranium and as of February 2010, 19.7% enriched uranium as well.

A similar event occurred at the beginning of 2011 when it was claimed that the computer worm "Stuxnet" had seriously damaged and slowed Iran's centrifuge uranium enrichment program during the latter part of 2009. I have refuted these claims elsewhere, and as can be seen from Table 1, Iran's uranium enrichment production was not disrupted in the latter part of 2009. Indeed during 2010 and the first part of 2011, it has significantly increased.[35] Again, this story appears to be nothing but more self-deception to avoid facing up to the great strides that Iran has made with its uranium enrichment program and how the time that it will take Iran to produce the HEU needed for a nuclear weapon has been steadily shrinking.

Putting aside these various efforts at self-deception and focusing on the calculations of when Iran might be able to produce HEU, we see that when assumptions are used that are similar to my own, Iran could produce the 20 kilograms of HEU needed for a nuclear weapon in approximately two months. This time will only continue to decrease as Iran's stockpile of 19.7% enriched uranium continues to grow and Iran's enrichment capacity continues to increase. It is important to keep in mind that Iran could produce this HEU in

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[33] Gregory S. Jones, "The Pleasures Of Self-Deception: The Fiction That Cyber Attacks Have Slowed Iran's Drive for Nuclear Weapons," January 26, 2011 http://www.npolicy.org/article_file/The_Pleasures_of_Self_Deception_Fiction.pdf

[34] Richard Stone, "Iran's Trouble With Molybdenum May Give Diplomacy a Second Chance," *Science*, Vol. 311, January 13, 2006, p.158.

[35] Gregory S. Jones, "The Pleasures Of Self-Deception: The Fiction That Cyber Attacks Have Slowed Iran's Drive for Nuclear Weapons," January 26, 2011 http://www.npolicy.org/article_file/The_Pleasures_of_Self_Deception_Fiction.pdf

two months only assuming that they made the decision to start the process today. In other words the two month estimate does not necessarily mean that Iran actually will have the HEU required for a nuclear weapon in two months. When Iran might actually take the step of producing HEU is discussed below.

IAEA Safeguards

Some of those who commented on my June 2, 2011 paper expressed the belief that regardless of how fast Iran could manufacture the HEU needed for a nuclear weapon, there was no reason for concern since Iran's enrichment facilities are under IAEA safeguards. Their view is that any attempt to produce HEU would be immediately detected and swift counteraction would be taken. Some have even expressed the mistaken belief that it would be the IAEA itself that would stop Iran from acquiring the HEU needed for a nuclear weapon.

Regarding this latter point, I am reminded of a quotation attributed to the former ruler of the Soviet Union, Joseph Stalin. Reportedly, when pressed to improve his relations with the Vatican, Stalin responded, "How many divisions does the Pope of Rome have?" The IAEA like the Pope does not have any divisions. It does not even a police force. By itself, it cannot take any military or law enforcement action to stop Iran or any other country from acquiring the fissile material required for nuclear weapons. Rather, according to the IAEA "…the objective of safeguards is the timely detection of diversion of significant quantities of *nuclear material*…"[36] [Emphasis in original]

As I wrote with my colleagues Albert and Roberta Wohlstetter over thirty years ago, "Safeguards do not mandate any penalties but <u>only</u> timely warning. [Emphasis in original] This is what affords at least the possibility of counteraction. Without even timely warning, we would have little besides reminiscence."[37]

A key issue is how timely "timely detection" needs to be. Presumably, "timely warning" allows for enough time to prevent safeguarded nuclear material or facilities from being used to produce the fissile material (HEU or plutonium) that could be used for nuclear weapons. The nominal detection times given by the IAEA are quite long.[38] Even for weapons ready material ("unirradiated direct-use"), the maximum time given by the IAEA for the detection of diversion is one month. For material such as Iran's current stockpiles of 3.5% and 19.7% ("indirect-use") the nominal maximum time is one year.

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[36] *The Structure and Content of Agreements Between The Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons*, INFCIRC/153, International Atomic Energy Agency, June 1972, p.9.

[37] Albert Wohlstetter, Gregory Jones, Roberta Wohlstetter, "Why the Rules Have Needed Changing", *Towards a New Consensus on Nuclear Technology*, Volume I, PH-78-04-832-33, Pan Heuristics, Prepared for U.S. Arms Control and Disarmament Agency, July 6, 1979, p.32. http://www.npolicy.org/files/19790706-TowardsANewConsensus-Vol01.pdf

[38] *IAEA Safeguards Glossary*, 2001 Edition, International Nuclear Verification Series, No. 3, International Atomic Energy Agency, Vienna, 2002, pp.20-21.

It is well recognized by the IAEA and others that safeguarding a centrifuge enrichment plant is very challenging even if the centrifuge enrichment plant is not in Iran and that inspections will have to be much more timely than once a year. This issue is the subject of much discussion and it is clear that there is not yet a consensus on how to successfully safeguard a centrifuge enrichment facility.[39] The European centrifuge enrichment consortium, URENCO, allows the IAEA to use a Continuous Enrichment Monitor at two of its plants which monitors the enrichment level in the gas in the product pipe as it is being produced. Such a technology would be useful in Iran but Iran apparently will not allow any type of remote monitoring including remote access to the IAEA's safeguards cameras.[40] Though parts of the FEP are under continuous video surveillance, the video footage can only be accessed in person at the site during an inspection. Instead of being able to monitor the FEP continuously in real-time, the IAEA must rely on periodic inspections at the site. These include routine inspections that seem to occur monthly as well as unscheduled inspections.

During March 2007 to February 2008, there were nine of these unannounced inspections.[41] The IAEA has probably increased the frequency of its unannounced inspections but they are unlikely to occur more than once or twice a month, meaning that there are probably one to three weeks between inspections. If Iran possessed a large enough stockpile of 19.7% enriched uranium, it could enrich this material to produce the 20 kilograms of HEU needed for a nuclear weapon in just two weeks. It is clear that Iran could finish this process in between inspections if it were lucky and at any rate there might be only one or two weeks of warning.

Since the IAEA's basic safeguards document, INFCIRC/153[42], was written back in 1972, the IAEA has realized that there are additional paths that countries can take to acquire the fissile material required for nuclear weapons. In particular there is the threat that clandestine facilities could be built to produce fissile material. The IAEA's original safeguards tended to focus "mainly on nuclear material and activities declared by the State. However, the discovery of Iraq's clandestine nuclear weapons programme (despite an existing comprehensive safeguards agreement between Iraq and the IAEA), as well as subsequent events in the DPRK, demonstrated that an effective verification regime must also focus on possible undeclared material and activities."[43] In May 1997 the IAEA

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[39] Peter Friend, "Conference Summary", *Symposium on International Safeguards*, IAEA, Vienna, 1 to 5 November, 2010, Roland Carchon, et al., "Load cell monitoring in Gas Centrifuge Enrichment Plants: Potentialities for improved safeguard verifications", *Nuclear Engineering and Design*, Vol. 241, 2011, pp. 349-356 and B. Boyer et al., "Gas Centrifuge Enrichment Plants Inspection Frequency and Remote Monitoring Issues for Advanced Safeguards Implementations," LA-UR 10-06169, IAEA-CN-184/139, 2010 Safeguards Symposium, Vienna, November, 2010.

[40] David Blair, "Iran's main nuclear plant expanding rapidly, says IAEA", *The Telegraph*, June 8, 2009.

[41] *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, IAEA, February 22, 2008, pp.7-8.

[42] *The Structure and Content of Agreements Between The Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons*, INFCIRC/153, International Atomic Energy Agency, June 1972.

[43] This and the other quotations in this paragraph are from: *Non-Proliferation of Nuclear Weapons & Nuclear Security: IAEA Safeguards Agreements and Additional Protocols*, IAEA, May 2005.

Board of Governors approved the Model Additional Protocol to Safeguards. As with all safeguards, the Additional Protocol is a voluntary agreement between the State and the IAEA. States that add the Additional Protocol to their safeguards agreement with the IAEA are required "to provide the Agency with an expanded declaration that contains information covering all aspects of their nuclear and nuclear fuel cycle activities. The States must also grant the Agency broader rights of access and enable it to use the most advanced technologies." The Additional Protocol requires a State to provide "access to any place on a nuclear site and to other locations where nuclear material is, or may be present."

Since 1998, 109 countries have had the Additional Protocol to their safeguards agreement with the IAEA enter into force.[44] Iran is not one of these countries. Up until 2003 Iran did not have the Additional Protocol as part of its IAEA safeguards agreement. However, in the aftermath of the revelation of its clandestine centrifuge enrichment program and Iran's voluntary halt to this program, Iran signed the Additional Protocol in December 2003. Normally there would have been a lag from the time of the signing until the Additional Protocol formally entered into force as Iran would first have had to ratify this Protocol. However, Iran indicated that the IAEA could start enforcing the Additional Protocol immediately even before it had formally entered into force. Iran never ratified the Additional Protocol. Instead in February 2006, just as Iran resumed work on its centrifuge enrichment program, Iran informed the IAEA that the IAEA could no longer enforce the Additional Protocol.[45] Consequently, while the IAEA can monitor the Iranian centrifuge facility at Natanz, it cannot conduct activities to find any clandestine enrichment facilities nor can it monitor Iran's centrifuge manufacturing facility to see if it is manufacturing additional centrifuges beyond what can be accounted for by Iran's safeguarded enrichment program.

A related issue is the time requirement for Iran to provide the IAEA design information on new facilities. Under Iran's safeguards agreement, design information is to "be provided as early as possible before nuclear material is introduced into a new facility". However, in February 2003, Iran agreed to the "modified Code 3.1" which requires Iran to provide design information on new facilities "as soon as the decision to construct or to authorize construction has been taken, whichever is earlier."[46] Therefore design information has to be provided before any new construction begins and any clandestine facility discovered under construction would automatically be a violation of Iran's safeguards agreement. However, in March 2007 Iran said that it was reverting to its old version of Code 3.1 which means that in its view Iran only must provide design information on new facilities not later than 180 days before the introduction of nuclear material into a facility. The IAEA says that Iran can not agree to the Additional Protocol

[44] As of June 21, 2011, see: "Safeguards and Verification: Status of Additional Protocols", http://www.iaea.org/OurWork/SV/Safeguards/protocol.htm

[45] *Implementation of the NPT Safeguards Agreement in the Islamic Republic of* Iran, GOV/2006/15, IAEA, February 27, 2006, pp.6-7.

[46] "Statement by the Legal Advisor", Meeting of the Board of Governors [IAEA], March 2009, http://www.armscontrolwonk.com/file_download/162/Legal_Adviser_Iran.pdf

and modified Code 3.1 and then unilaterally stop complying but despite UN Security Council resolutions calling for Iran to resume its compliance, Iran has not.

Nor is this just an academic concern. In September 2009, Iran concerned that its activities had been discovered, was forced to admit that it was building a clandestine centrifuge enrichment plant at Qom. The IAEA said that this was a violation of its modified Code 3.1 obligations but Iran contends that under its old Code 3.1 obligations it only had to inform the IAEA 180 days before nuclear material was introduced into the centrifuges at Qom. Since this has still not happened, Iran claims that it has committed no violation. Further complicating matters, foreign sources report that the construction of the facility at Qom started in 2006, back when Iran was still supposedly complying with the modified Code 3.1 but Iran claims that the construction did not start until after March 2007.

Without Iran's compliance with the Additional Protocol and the modified Code 3.1, there is no way that the IAEA can assure that additional clandestine centrifuge enrichment plants are not being constructed or are not in operation. In its recent statements, the IAEA has admitted to as much.[47] This is significant because, as was shown above, with a clandestine centrifuge enrichment plant containing about 3,800 of its current centrifuges, Iran could produce about one weapon's worth of HEU a year.

While the IAEA has been clear about the threat posed from possible clandestine Iranian centrifuge enrichment facilities, it has not been willing to admit the seriousness of the threat posed by Iran's centrifuge enrichment facilities that are under safeguards. As was shown in the calculations above, Iran's current centrifuge enrichment facilities allow Iran to quickly produce the HEU needed for nuclear weapons. As Iran continues to expand its centrifuge enrichment facilities and adds to its stockpiles of 3.5% and 19.7% enriched uranium, this time will grow ever shorter. At what point does the time become too short to provide "timely warning"?

As I wrote with my colleagues Albert and Roberta Wohlstetter and Henry Rowen in 1979:

> "…bilateral and international inspection systems do indeed need improvement, but if such improved inspection is to be more than a facade for a possible steady advance toward nuclear explosive materials by states that do not presently have them, the facilities, processes and stocks inspected must be far enough away from yielding bomb material to make timely warning feasible. Unless sensitive technologies are restricted,

[47] "While the Agency continues to verify the non-diversion of declared nuclear material at the nuclear facilities and LOFs declared by Iran under its Safeguards Agreement, as Iran is not providing the necessary cooperation, including by not implementing its Additional Protocol, the Agency is unable to provide credible assurance about the absence of undeclared nuclear material and activities in Iran, and therefore to conclude that all nuclear material in Iran is in peaceful activities." *Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions in the Islamic Republic of Iran*, GOV/2011/29, May 24, 2011, p.9.

> “effective safeguards” in the sense defined by the IAEA and the NPT are literally infeasible.”[48]

To take an extreme case, imagine that a country has a number of HEU metal spheres under safeguards. Though years might go by where the IAEA verified that no diversion had taken place, no safeguards arrangement could stop the country from suddenly taking these metal spheres, placing them into nuclear weapons and using these weapons. This whole process could take place in a matter of hours, far too short a time for a timely warning. Indeed in this case, a nuclear explosion, not the IAEA raising the alarm, would be the indicator that these HEU metal spheres were no longer under safeguards. Though this example might seem far fetched, in fact Italy, for many years, had a research reactor (Tapiro) which utilized about 24 kilograms of HEU in a cylindrical metallic form.[49]

So where should the boundary line be? The IAEA has apparently accepted that Iran can produce 19.7% enriched uranium. As I calculated above, once Iran has accumulated a stockpile of about 160 kilograms of such material, it could produce 20 kilograms of HEU in less than two weeks. It is hard to imagine that such short time interval would provide timely warning. And this assumes that the IAEA would sound the alarm as soon as Iran started producing HEU. But if Iran continued to keep the HEU under safeguards would the IAEA in fact sound the alarm? After all, various countries including non-nuclear weapon states have research reactors that utilize HEU.[50] If Iran said that it wanted to build such a research reactor and did not remove the HEU from safeguards, it is not at all clear that the IAEA would object. Yet at any time Iran could suddenly remove the HEU from safeguards and convert it into metal spheres suitable for use in nuclear weapons. This process could occur in less than one week which is far too short a time to provide timely warning.

It is well past time for the IAEA to explicitly define the boundary lines between materials and technologies that are too close to nuclear weapons to be effectively safeguarded (in the sense that timely warning cannot be provided) and those materials and technologies that can be effectively safeguarded. It could well be that any centrifuge enrichment plant with a significant enrichment output, when combined with stocks of low enriched uranium would fall into the former category and are inherently unsafeguardable. Since sizable centrifuge enrichment facilities are located in many countries (such as Brazil and Japan), this conclusion would have serious implications outside of Iran.

Henry Sokolski has raised the same issues and made a similar recommendation:

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[48] Albert Wohlstetter, Gregory Jones, Roberta Wohlstetter, Henry S. Rowen, “Summary”, *Towards a New Consensus on Nuclear Technology*, Volume I, PH-78-04-832-33, Pan Heuristics, Prepared for U.S. Arms Control and Disarmament Agency, July 6, 1979, p.2. http://www.npolicy.org/files/19790706-TowardsANewConsensus-Vol01.pdf

[49] Albert Wohlstetter, Thomas A. Brown, Gregory Jones, David C. McGarvey, Henry Rowen, Vince Taylor, and Roberta Wohlstetter, *Swords from Plowshares*, University of Chicago Press, Chicago, 1979, p.153.

[50] Alan J. Kuperman, “Global Phase-Out of Bomb-Grade Uranium,” Presentation at the American Association for the Advancement of Science (AAAS), Washington, DC, May 9, 2011, http://blogs.utexas.edu/nppp/files/2011/05/LBJ-PRP-HEU-2011-May-DC.pdf

> "***Distinguish between what can be effectively safeguarded, and what can, at best, only be monitored.*** [Emphasis in original]
>
> Currently, the IAEA is unable to provide timely warning of diversions from nuclear fuel-making plants (enrichment, reprocessing, and fuel processing plants) utilizing nuclear materials directly usable to make bombs….The IAEA has yet to concede these points by admitting that although it can monitor these dangerous nuclear activities, it cannot actually do so in a manner that can assure *timely detection* of a possible military diversion—the key to an inspection procedure being a safeguard against military diversions."[51] [Emphasis in original]

A related issue is how short must the time to produce HEU become before a country effectively does have nuclear weapons? As I wrote with my colleagues Albert and Roberta Wohlstetter in 1979:

> "If in fact, technological transfers can bring a "nonnuclear weapon state" within weeks, days or even hours of the ability to use a nuclear explosive, in the operational sense that "nonnuclear weapon state" will have nuclear weapons. The point is even more fundamental than the fact that effective safeguards mean timely warning. A necessary condition for having timely warning is that there be a substantial elapsed time. But if there is no substantial elapsed time before a government may use nuclear weapons, in effect it <u>has</u> them. [Emphasis in original]
>
> The point may be driven home if we recall that in 1947, for example, the United States stored its plutonium weapons in disassembled form. Moreover, since the design was quite primitive and used much more inconvenient components than are commercially available today, the process of putting the weapon together took many hours. [e.g. several days[52]] In fact, it took a longer time than would be needed today by a well prepared government laboratory to make highly concentrated fissile material ready for insertion in a nonnuclear assembly for compressing it rapidly. The United States did have nuclear weapons in 1947. And if the rules are relaxed enough, so can nonnuclear weapon states today."[53]

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[51] Henry Sokolski, "Assessing the IAEA's Ability to Verify the NPT," *Falling Behind: International Scrutiny of the Peaceful Atom*, Strategic Studies Institute, U.S. Army War College, Carlisle, PA, February 2008, pp.7-8.

[52] Albert Wohlstetter, "Spreading The Bomb Without Quite Breaking The Rules," *Foreign Policy*. No. 25 Winter 1976-77, p.48.

[53] Albert Wohlstetter, Gregory Jones, Roberta Wohlstetter, "Why the Rules Have Needed Changing", *Towards a New Consensus on Nuclear Technology*, Volume I, PH-78-04-832-33, Pan Heuristics, Prepared for U.S. Arms Control and Disarmament Agency, July 6, 1979, pp.36-37. http://www.npolicy.org/files/19790706-TowardsANewConsensus-Vol01.pdf

Now, 32 years later, little has changed. There are some who take comfort in the fact that thus far the IAEA has never reported that Iran has diverted material from safeguards. However, unless the IAEA makes clear that some materials and technologies cannot be effectively safeguarded, under the current rules Iran can move ever closer to a nuclear weapons capability without needing to divert any material from safeguards until it is far too late.

Even if the IAEA were to sound the alarm, then what? Though there is often talk of swift action being taken to stop Iran from obtaining nuclear weapons, that has not been the case up to now. After all, the IAEA has already reported repeated violations of Iran's safeguards agreement, including activities that indicate the development of nuclear weapons but thus far all that has been done is that the UN Security Council has passed five resolutions which in part have called for Iran to stop its uranium enrichment effort. Iran's rising enriched uranium production, shown in Table 1, demonstrates how ineffective these resolutions have been.

The ultimate response to an IAEA alarm would be some sort of military action but this is rather unlikely. Israel, which has struck both Iraq (in 1981) and Syria (in 2007) to disable nuclear reactors involved in efforts to produce the fissile material for nuclear weapons, is considered to be the most likely candidate for such action. Ironically, however, Israel's strike on Syria in 2007 illustrates that it is unlikely to strike Iran. As its actions against Syria showed, if Israel perceives a threat, it is likely to strike quickly, without any preliminaries such as appeals to the international community. Iran restarted its centrifuge enrichment program in 2006, yet over five years later, Israel has taken no action. By this inaction Israel appears to have decided that Iran's centrifuge enrichment program is either too far away or too well dispersed or protected to be effectively struck.

Though many who commented on my June 2, 2011, paper mistakenly believed that I was calling for an immediate invasion of Iran, such an option is, in fact, an obvious nonstarter. After ten years of war in Afghanistan and Iraq, the U.S. is too war-weary and financially exhausted to consider such an action, especially since Iran is much larger and more populous than either Iraq or Afghanistan. The U.S. could try to undertake limited strikes against Iran's centrifuge enrichment program, but isolated strikes would only delay the program and drive it further underground. Only a sustained campaign would likely be able to stop Iran's centrifuge program, but this could easily lead to an unwanted long-term war with Iran. Therefore, the U.S. does not seem to have any realistic military options for eliminating Iran's centrifuge enrichment program.

At any rate, under the present circumstances, it does not seem as though the IAEA is going to raise any specific alarm about Iran's centrifuge enrichment program. Rather, Iran will keep its enrichment program under IAEA safeguards and simply keep reducing the time required for it to produce HEU by continuing to expand its centrifuge enrichment capacity and by enlarging its stockpiles of 3.5% and 19.7% enriched uranium. As my calculations above have shown, Iran can currently produce a weapon's worth of HEU in about two months. This is already probably too short a time for the IAEA to provide timely warning and as this time drops from two months to a few weeks over the next year or two, the world will have to start treating Iran as a de facto nuclear weapon state.

How Long Will It Take for Iran to Produce the Non-Nuclear Components for a Nuclear Weapon?

Any effort to obtain nuclear weapons must consist of two parts: (1) the production of the fissile material (HEU or plutonium) needed for the weapon; and (2) the manufacture of the high explosive components needed to detonate the weapon. For all prior nuclear weapon programs, the production of the fissile material has been by far the most difficult, most time consuming and most expensive part of the endeavor.[54]

However, some U.S. government officials have made statements that run counter to this historical experience. They have contended that while Iran might be able to produce the HEU required for a nuclear weapon, it could take Iran a number of years to produce the non-nuclear components for a nuclear weapon. In April 2010 General James Cartwright, Chairman of the Joint Chiefs of Staff offered an extreme example of this view. In congressional hearings, he said that even if Iran were to already have the HEU necessary to produce a nuclear weapon, it would take Iran "three to five years" to be able to produce a nuclear explosive device.[55] Surprisingly, Cartwright called this "an historical estimate" based on other countries' experiences though he did not specify which countries he had in mind. Unfortunately, a look at the historical experience of the U.S. along with information provided by the IAEA shows Cartwright's statement to fall into the category of a pleasant self-deception that was discussed above.

For most nuclear weapons, the HEU is detonated using the implosion method. The HEU is surrounded by explosives and when they are set off, the HEU is compressed to a supercritical mass which then produces a nuclear explosion. As I have written elsewhere, the U.S. was able to develop implosion-type nuclear weapons in only eleven months during 1944-1945.[56] Though today Iran would not have the talent and resources available to the Manhattan Project, it would be starting from a far better position than the U.S. did. In 1944, no one knew whether or how the implosion method could work. Today it is not only well known that such weapons work but also there are descriptions of such weapons and pictures showing their general construction. Additionally, knowledge of explosives as well as computing power are far superior today than they were 67 years ago when the U.S. undertook this effort.

Further, Iran would not be starting from scratch. According to the 2007 National Intelligence Estimate (NIE), Iran was developing nuclear weapons until the fall of 2003.[57]

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[54] *Ibid.*, p53.
[55] Hearing of the Senate Armed Services Committee; Subject: U.S. Policy towards the Islamic Republic of Iran, April 14, 2010.
[56] Gregory S. Jones, "When Could Iran Have the Bomb? An Analysis of Recent Statements That Iran is 3 to 5 Years Away", April 26, 2010, http://www.npolicy.org/article.php?aid=94&rt=&key=Gregory%20S.%20Jones&sec=article
[57] National Intelligence Estimate, "Iran: Nuclear Intentions and Capabilities," National Intelligence Council, November 2007, p.6, http://www.dni.gov/press_releases/20071203_release.pdf

In addition, Iran may have received warhead design details from either Pakistan or North Korea. Since Pakistan is thought to already have a viable missile warhead design (believed to have been provided by the Chinese), such aid would be particularly useful to Iran. Supporting this view is an internal IAEA document from 2009 which said:

> "The Agency further assesses that Iran has sufficient information to be able to design and produce a workable implosion nuclear device based upon HEU as the fission fuel. The necessary information was most likely obtained from external sources and probably modified by Iran. The Agency believes that non-nuclear experiments conducted in Iran would give confidence that the implosion system would function correctly.[58]"

Further in June 2011, Yukiya Amano, the director general of the IAEA said that the agency had received "further information related to possible past or current undisclosed nuclear-related activities that seem to point to the existence of possible military dimensions to Iran's nuclear program."[59] He went on the say "The activities in Iran related to the possible military dimension seem to have been continued until quite recently."

It is also important to clear up a mistaken belief regarding how nuclear weapons are developed. A number of sources seem to believe that Iran would have to develop a nuclear weapon sequentially, first producing the HEU and only then being able to develop the non-nuclear weapon components. But this is a fundamental misunderstanding of how nuclear weapons are developed. The production of the fissile material for a nuclear weapon and the production of the non-nuclear components needed to detonate the fissile material can be carried out in parallel. This essential fact has been known since the beginning of the nuclear era.

One of the clearest statements of how nuclear weapons are developed can be found in the official British history of its nuclear weapons program. In a memo dated November 1, 1946, William Penney who was to lead the British effort, outlined how the task could be accomplished. According to the British history:

> "He said that the manufacture of an atomic bomb of present design fell naturally into two parts: firstly the production of the active material and secondly the ordnance part, that is, the manufacture and assembly of the components causing the explosion of the active material. The second part of the work could be begun and completed without the need to use fissile material at any stage."[60]

[58] "Excerpts from Internal IAEA Document on Alleged Iranian Nuclear Weaponization," Institute for Science and International Security, October, 2, 2009, http://www.isisnucleariran.org/assets/pdf/IAEA_info_3October2009.pdf

[59] Fredrik Dahl and Sylvia Westfall, "New data suggests Iran military link-U.N. atom chief," *Reuters*, June 6, 2011.

[60] At the time the memo was so highly classified that Penney had to type it himself. See: Margaret Gowing, assisted by Lorna Arnold, *Independence and Deterrence: Britain and Atomic Energy, 1945-1952*, Volume I, Policy Making, St. Martin's Press, New York, 1974, p.180.

Therefore, the eleven months that it took the U.S. to develop an implosion nuclear weapon in World War II should be considered an upper bound of the time it would take Iran to develop such a weapon if it were to decide to undertake an all-out effort. The actual time could be considerably less especially if what the IAEA says is true and Iran not only already has enough information to design a nuclear weapon but also is continuing to work on the development of nuclear weapons. Just as Iran's continuing enrichment efforts are reducing the time required for it to produce HEU should it decide to do so, its weaponization work is reducing the time needed for it to produce the non-nuclear components for a nuclear weapon. Iran's development of the non-nuclear components for its nuclear weapons need not wait for Iran to first produce HEU but rather Iran can, and probably is, developing these non-nuclear components now.

Does Iran Even Have a Nuclear Weapons Program?

Some, including former head of the IAEA Mohamed ElBaradei have expressed doubts that Iran has any nuclear weapons program at all.[61] At the extreme some hold the view that Iran is simply exercising its right to utilize peaceful nuclear energy. But while elements of Iran's nuclear program have been used in the peaceful nuclear programs of other countries, in the overall context of Iran's nuclear program, it is difficult to consider Iran's nuclear program as being a simple exercise of peaceful nuclear energy.

Take, for example, Iran's production of 3.5% enriched uranium. Certainly other countries have produced such enriched uranium and used it as fuel for light water nuclear power reactors (this type of nuclear power reactor is the most common type used today). However, there are two problems with seeing Iran's current effort as being intended for the production of power reactor fuel. First, Iran's enrichment capacity is not close to being large enough to fuel a nuclear power reactor. Iran would have to have an enrichment capacity of between 10 and 30 times greater than it currently has to be able to supply fuel for even one nuclear power reactor. Second, Iran has no nuclear power reactors for which it needs to supply fuel. Iran has just started a nuclear power reactor at Bushehr but this reactor was supplied by the Russians and part of Iran's contract with Russia requires all of the fuel for the reactor to be supplied by Russia. Without any reactor requiring 3.5% enriched uranium, Iran is simply stockpiling this material, which as was shown above, can be used to quickly produce the HEU required for a nuclear weapon.

Not only is Iran pursuing centrifuge enrichment which could easily be used to produce the HEU needed for a nuclear weapon, but it has also been building what Iran has termed a research reactor (the IR-40). This reactor, which uses natural uranium fuel and a heavy water moderator, is an ideal plutonium production reactor. Indeed, reactors of this type have supported nuclear weapons efforts in Israel, India, Pakistan and Taiwan. Further, in 2003, Ghalamreza Aghazadeh, the head of the Atomic Energy Organization of Iran, made statements implying that he viewed the centrifuge enrichment effort and the building of

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[61] Seymour M. Hersh, "IRAN AND THE BOMB; Annals of National Security", *The New Yorker*, Vol.87, No.16, June 6, 2011

the research reactor as parallel efforts and it was important that one of them succeed.[62] Such a view would only make sense if these undertakings were part of a nuclear weapons effort, where they would be parallel sources of fissile material (either HEU or plutonium).

Iran has also taken various actions designed to make monitoring of its nuclear program by the IAEA more difficult and in some cases Iran has clearly violated its IAEA safeguards agreement. Albright has documented these issues in detail.[63] Here are the highlights.

Prior to 2003, Iran conducted secret centrifuge uranium enrichment that was a clear violation of Iran's safeguards agreement with the IAEA. In an attempt to hide one facility where this activity had taken place, Iran leveled it, hauled away the rubble, scraped the dirt away and then built a recreational facility on top of it.

As was discussed above, despite agreeing to enhance its IAEA safeguards in 2003 by implementing the Additional Protocol and the modified Code 3.1, in 2006 and 2007, Iran suddenly stopped the IAEA from enforcing these parts of its safeguards agreement. According to the IAEA, Iran is not permitted to make unilateral changes to its safeguards agreement.

In 2009 Iran was forced to reveal that it was building a clandestine centrifuge enrichment facility at Qom. The size of this facility (roughly 3,000 centrifuges) is close to the size that would allow Iran to produce about one nuclear weapon's worth of enriched uranium per year.[64]

Iran has continued to defy repeated UN Security Council resolutions. These resolutions have called for Iran to suspend all enrichment-related activities and without delay fully and without qualification comply with the modified Code 3.1 as well as promptly ratify the Additional Protocol.

Some who hold the view that Iran does not have a nuclear weapons program have attached much significance to statements that Iran has yet to formally decide to produce nuclear weapons. Such statements were made in the early part of 2011 as part of the discussion about the new NIE. For example the Director of National Intelligence, James Clapper made a clear statement to this effect in his testimony to Congress.[65] Clapper went on to say that by pursuing centrifuge enrichment, Iran was "keeping open the option to develop nuclear weapons."

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[62] David Albright, *Peddling Peril*, Free Press, New York, 2010, pp.192-193.
[63] *Ibid.*, in particular chapter nine and David Albright and Jacqueline Shire, "Misconceptions about Iran's Nuclear Program," July 8, 2009, http://www.isisnucleariran.org/static/297/
[64] If they have the same separative capacity as Iran's current centrifuges (0.89 SWU per year), then 3,000 centrifuges could produce 20 kilograms of HEU in about 15 months.
[65] Mark Hosenball, "U.S. Intelligence: Iran leaders reopened nuke debate," *Reuters*, February 17, 2011.

That Iran's leadership has not yet issued a specific order for a nuclear weapon to be produced could well be true. However, Clapper's second statement that Iran was "keeping open the option" is a dangerous understatement. As has been discussed above, Iran is doing more than just keeping open the option—something that implies a static situation. Iran has been steadily drawing closer to a nuclear weapons capability by continually reducing the amount of time that it would take to produce HEU, continuing work related to the actual manufacture of nuclear weapons, and conducting secret ballistic missile tests that could be used to develop a nuclear weapons delivery capability.

While Iran's steady movement towards a nuclear weapons capability is bad enough, what is even worse is that this movement makes it increasingly likely that Iran will then decide to actually produce a nuclear weapon. As was discussed above, the IAEA has not clearly stated what activities might be benign and what activities can not be effectively safeguarded, creating the ambiguity (however slight) that Iran's actions might have some peaceful purpose. I examined this issue in detail back in 1979 with my colleagues Albert and Roberta Wohlstetter:

> "The ambiguities, however, can function in many different ways in various governments to make the decision for a weapon ultimately more likely. In some governments, political leaders are likely to find such a decision easier if they can inch toward such a capability rather than try to reach it in one leap."
>
> An examination of the history of decisions on nuclear energy in a good many countries confirms that preservation of ambiguity as to the civilian or military applications for a program matters a great deal. It makes it possible to drift into a military program without making a positive decision until very late… <u>In particular, the legitimate acquisition of large quantities of highly concentrated fissile material has facilitated the decision to make bombs in the past.</u> [Emphasis in original]
>
> Three of the last four countries to make and test nuclear explosives—that is, the three in which the evidence is public—The United Kingdom, France, and India—decided to produce and separate plutonium well before they overtly decided on a nuclear explosives program. The decision to get plutonium carried these governments along most of the path toward a bomb, but left it ambiguous as to just where the path would end. The ambiguity may, at the early stages, have reflected some uncertainties and indecision in the governments themselves, or it may, in the later stages in particular, have been ambiguous only so far as the public is concerned."[66]

[66] Albert Wohlstetter, Gregory Jones, Roberta Wohlstetter, "Why the Rules Have Needed Changing", *Towards a New Consensus on Nuclear Technology*, Volume I, PH-78-04-832-33, Pan Heuristics, Prepared for U.S. Arms Control and Disarmament Agency, July 6, 1979, p.80-81. http://www.npolicy.org/files/19790706-TowardsANewConsensus-Vol01.pdf

Another country that fell into this category was Nazi Germany. Hitler never issued any directive for a nuclear weapon to be produced but this does not mean that nuclear developments in Nazi Germany were benign. Obviously, the efforts to produce large amounts of heavy water in Norway were part of a German effort to produce plutonium for nuclear weapons.

Though Iran has yet to actually produce HEU, it is drawing ever closer. Iran has probably already reached the point where the IAEA can not effectively (in the sense of being able to provide timely warning) safeguard Iran's centrifuge enrichment facilities and its stocks of 3.5% and 19.7% enriched uranium. As Iran draws closer to a nuclear weapons capability, it becomes increasingly likely that Iran will move the last remaining distance and actually acquire nuclear weapons.

A related view attributed to the U.S. Defense Intelligence Agency (DIA) by Hersh is that Iran's nuclear weapons effort before 2003 was not aimed at the West but rather at Iraq and therefore Iran no longer has a need for a nuclear weapons program.[67] There are two problems with this view.

First, it should be remembered that the Manhattan Project was aimed at Nazi Germany's nuclear weapons effort, not at Japan. But this fact did the people of Hiroshima and Nagasaki very little good. Second, this view does not explain why Iran has renewed it centrifuge enrichment effort since 2006. As has been discussed above, it is very hard to see the current nuclear developments in Iran as benign when Iran is moving ever closer to a nuclear weapons capability by significantly and purposefully shortening the time that would be required for it to acquire nuclear weapons.

Others hold the view that the current concern about Iran is simply a repeat of the mistaken claims about Iraq in 2002. Since intelligence estimates were wrong then, why should we be concerned now? This view fails to distinguish the key difference between the two cases. In 2002 the U.S. had very little information about Iraq's WMD programs. The current situation with Iran is quite different. The IAEA's inspections provide hard information about Iran's centrifuge enrichment capability, and the size of Iran's enriched uranium stockpiles. When Iran was allowing the IAEA to implement the Additional Protocol, the IAEA found clear evidence of nuclear weaponization as well. For decades experts have long recognized that centrifuge enrichment poses a serious nonproliferation risk. As was discussed above, I wrote about the dangers of centrifuge enrichment over 32 years ago, long before there was any concern about Iran's nuclear program.

Retired DIA analyst W. Patrick Lang has expressed a variant of the view that the current concerns about Iran are overblown as were concerns about Iraq in 2002. Lang claims that in 2002 intelligence analysts were subjected to "enormous pressure" to find that Iraq had WMD but that in the case of Iran they are refusing to sign up this time.[68] The problem with this view is that the 2002 intelligence failure has been examined in detail by a

[67] Seymour M. Hersh, "IRAN AND THE BOMB; Annals of National Security", *The New Yorker*, Vol.87, No.16, June 6, 2011.
[68] *Ibid.*

commission of distinguished intelligence experts.[69] The commission found no evidence that intelligence analysts were pressured by policymakers to produce a specific outcome and the analysts themselves stated that there had been no political pressure to cause them to skew their judgments.[70] Rather the commission faulted the analysts themselves, saying that their mistaken judgments in 2002,

> "…were the product of poor intelligence collection, an analytical process that was driven by assumptions and inferences rather than data, inadequate validation and vetting of dubious intelligence sources, and numerous other breakdowns in the various processes that Intelligence Community professionals collectively describe as intelligence 'tradecraft.' In many ways, the Intelligence Community simply did not do the job that it exists to do."[71]

It is understandable that intelligence analysts would want to try to rewrite this sorry history but regarding Iran, it appears that they are just trading one mistake for another. Concerns about Iran are not based on dubious sources such as "Curveball" but rather the hard evidence provided by IAEA inspections.

The bottom line is the Iran does indeed have a nuclear weapons program. Its expanding centrifuge enrichment capacity, and stockpiles of 3.5% and 19.7% enriched uranium as well as its likely continuing research on the non-nuclear components of nuclear weapons is moving Iran ever closer to a nuclear weapons capability. Though Iran's leadership may have not yet have specifically decided to develop nuclear weapons, the U.K., France, India and Nazi Germany all had nuclear weapons programs before their governments decided to produce nuclear weapons. The U.K., France and India all went on to make such a decision and have actually produced nuclear weapons. This underscores the point that as Iran's efforts move it closer and closer to a nuclear weapons capability, it is increasingly likely that Iran will make the decision to produce nuclear weapons.

When Might Iran Actually Acquire Nuclear Weapons and Why Should We Care?

It is important to distinguish between the words "could" and "will." As was shown above, Iran using its existing centrifuges at the FEP as well as its stockpiles of 3.5% and 19.7% enriched uranium *could* produce the HEU required for a nuclear weapon in about two months *if* it decided to start the process today. Further, this time interval is shrinking as Iran continues to expand its enrichment capacity and enlarge its stockpiles of enriched uranium. The amount of time required for Iran to produce HEU is important, since it determines the adequacy of IAEA safeguards and whether they can provide "timely warning." It is also important since the shorter the time interval, the more likely it is that Iran will make the decision to take the final step and actually produce nuclear weapons.

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[69] "The Commission on the Intelligence Capabilities of the United States Regarding Weapons of Mass Destruction," Report to the President of the United States, March 31, 2005, http://govinfo.library.unt.edu/wmd/report/wmd_report.pdf
[70] *Ibid.*, p.11.
[71] *Ibid.*, p.47.

However, this does not mean the Iran *will* actually produce nuclear weapons in just two months. This distinction was lost on many who commented on my June 2, 2011 paper and mistakenly believed that I was saying that Iran would have nuclear weapons in August of 2011.

When might Iran actually acquire nuclear weapons? The answer to this question must of necessity be more speculative than the other portions of this paper and depends in part on what is exactly meant by "acquire nuclear weapons". It is most likely that Iran's acquisition of nuclear weapons might play out slowly but inexorably in a manner similar to that of Pakistan. It is instructive to review the history of Pakistan's acquisition of nuclear weapons.

In 1983, Pakistan began to enrich uranium using centrifuges. At the time, Pakistan pledged to the U.S. that it would not produce any uranium with an enrichment greater than 5%. By 1987 Pakistan had broken this pledge and produced HEU. In 1985, the U.S. Congress had passed the Pressler Amendment which conditioned U.S. aid to Pakistan on the U.S. president certifying that Pakistan did "not possess a nuclear explosive device." From 1987 through 1989, Presidents Reagan and Bush continued to provide the certification but in 1990 President Bush could not. In 1991 Pakistan's Prime Minister Sharif froze Pakistan's production of HEU but continued the production of LEU. In 1998 Pakistan tested two nuclear devices in response to nuclear tests in India.

After these nuclear tests, Pakistan began to increase it stocks of HEU and plutonium needed for nuclear weapons. Pakistan resumed its production of HEU and by using its stocks of LEU, it was able to quickly produce significant quantities of HEU. Indeed the process of stockpiling LEU and then converting it to HEU produced the same amount of HEU as if Pakistan had continued to produce HEU throughout the 1990s. Also in 1998 Pakistan started the operation of the Khushab-1 which is a plutonium production reactor. Throughout the last decade Pakistan is believed to have expanded its production of HEU and started a second plutonium production reactor near the beginning of 2010. A third plutonium production reactor may start operation this year. Currently Pakistan is believed to have an arsenal of about 100 weapons and according to a recent report: "Despite its political instability, Pakistan continues to steadily expand its nuclear capabilities and competencies; in fact, it has the world's fastest-growing nuclear stockpile."[72]

A key difference between Pakistan's situation in the 1980s and 90s and that of Iran today is that Iran's main nuclear program is under IAEA safeguards. But this fact makes less of a difference than one might think. Even if Iran plans to use its stockpiles of 3.5% and 19.7% enriched uranium as well as the centrifuges at the FEP to produce HEU for nuclear weapons, Iran need not violate its safeguards unless it actually wants to test or use a nuclear weapon.

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[72] Hans M. Kristensen and Robert S. Norris, "Pakistan's nuclear forces, 2011," *Bulletin of the Atomic Scientists*, Vol. 67, No. 4, 2011, p 91.

As was discussed above, Iran is steadily moving closer to a nuclear weapons capability without needing to provoke a crisis with the West. It is continuing to expand its centrifuge enrichment capacity and increase the amount of 3.5% enriched uranium it produces each month. By the beginning of next year it will be in a position to quickly produce the HEU for not just one but two nuclear weapons. At the same time, it has already taken the first step to convert the 3.5% enriched uranium into HEU by converting the 3.5% enriched uranium into 19.7% enriched uranium with the approval of the IAEA. Though its current rate of 19.7% enriched uranium production is fairly low, in June 2011, Iran announced plans to triple its production of this enriched uranium.

Over the next few years, Iran may also try to keep probing at the boundary line between what is acceptable and what is not. It may even try to start producing at least limited quantities of HEU, again claiming that such material is needed for peaceful research. At any rate, Iran will be able to shorten the time required for it to produce the 20 kilograms of HEU needed to produce a nuclear weapon from the current two months to only a week or two. At the same time, Iran will accumulate enough enriched uranium stocks to be able to quickly produce between two and five weapons and it could finish the production of the non-nuclear weapons components. At this point, which will likely occur sometime between 2012 and 2015, Iran will certainly be a de facto nuclear weapon state, even though it will not have officially violated IAEA safeguards or detonated a nuclear weapon.

Nor must Iran necessarily rely on its safeguarded nuclear program to produce HEU. As was discussed above, Iran could be building or could have already built a clandestine centrifuge enrichment plant that processes natural uranium into HEU. Such a plant could already be in operation and perhaps has already produced enough HEU for a nuclear weapon. All Iran would need to do is finish the production of the non-nuclear weapon components to have a complete nuclear weapon. It might take Iran only a few months to do so, once it decided to make a concerted weaponization effort. Even then Iran may not become an overt nuclear weapon state. Rather, like Pakistan, between the years 1990 and 1998, Iran might possess nuclear weapons but not claim an overt nuclear weapons status.

One might ask why it seems inevitable that Iran will obtain nuclear weapons if Iran might not possess such weapons for several months or even several years. The reason is that Iran has already managed to sufficiently shorten the time it needs to obtain a nuclear weapon so that if Iran were to be confronted with strong Western pressure to stop its push for nuclear weapons, it would most likely dash ahead to obtain a nuclear weapon rather than comply with Western demands. This is in strong contrast to Libya's position in 2003, when it efforts to obtain nuclear weapons were discovered by the West. Since Libya was still many years away from a nuclear weapons capability, it had no choice but to give up its effort.

Why then should we be concerned about Iran actually obtaining nuclear weapons? Some hold the view that since the U.S. can deter Iran from using nuclear weapons, there is not much of a problem even if Iran were to obtain a small nuclear arsenal. Again, Pakistan's behavior as a nuclear state provides valuable insight into the reasons to be concerned by

Iran's acquisition of nuclear weapons. When Pakistan first exploded nuclear weapons in 1998, there were some who believed that since India has nuclear weapons as well, it would not be that difficult for the two countries to maintain a stable deterrence and therefore Pakistan's nuclear weapons would pose little threat to the peace and stability of the world. In the intervening 13 years it has become apparent that the stability of deterrence between India and Pakistan was not the problem but there were two other issues instead.

First, and by far the biggest worry regarding Pakistan's nuclear weapon program relates to whether Pakistan can keep control of these weapons. There are two types of loss of control, involuntary and voluntary.

Regarding involuntary loss of control, Pakistan has been racked by growing political instability and the term "failed-state" is increasingly being applied to Pakistan. The country has sold centrifuge enrichment technology to Iran, North Korea and Libya. The Pakistani government claims that it had no idea that sales of this key nuclear technology were taking place even though they occurred over the span of many years. Similarly, it claims to have had no idea that Osama bin Laden was running Al Qaeda from deep inside Pakistan for the past six years. Of further concern is the rise of radical Islam in Pakistan. One recent demonstration of this was the assassination of the Governor of Punjab, Salman Taseer, for opposing Pakistan's archaic blasphemy law. The assassin was Taseer's own security guard. Tens of thousands of Pakistanis have demonstrated in support of the assassin.

Regarding voluntary loss of control, there is increasing skepticism that Pakistan was totally ignorant of the sales of centrifuge enrichment technology and of Osama bin Laden's presence in Pakistan. There is a growing belief that at least some high-level military and/or government officials were either involved in these transactions or were induced to "look the other way." This view has gained strength as it has become clear that U.S.-supplied intelligence to Pakistan has been used to alert and protect elements of the Taliban who are using Pakistan as a base to kill American soldiers in Afghanistan.[73] Given Pakistan's conduct in these matters, it not so far-fetched to suppose that Pakistan, which already has about 100 nuclear weapons, could sell some nuclear weapon components or even one or two nuclear weapons

In contrast to Pakistan, there is no need to wait for the rise of radical Islam in Iran, as it is already there. So is political unrest, which has involved not only the pro-democracy movement but also infighting among the political elites. In such a situation, it is not inconceivable that Iran might involuntarily lose control of it nuclear weapons.

Also in contrast to Pakistan, ideology rather than money is a far more likely reason that Iran might relinquish control of some of its nuclear weapons. Iran has already stated that Israel needs to be removed from the map. Hamas would not hesitate if it were given the

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[73] Eric Schmittt and Mark Mazzetti, "Pakistan Arrests C.I.A. Informants in Bin Laden Raid," *The New York Times*, June 14, 2011.

opportunity to attack Israel with nuclear weapons. A single nuclear weapon smuggled into Tel Aviv and exploded could have a devastating effect on the entire country.

The second concern about Pakistan's nuclear weapons program is that Pakistan feels that its weapons provide it with a shield so that it can conduct provocative attacks on India. This is contrary to the original view that nuclear weapons in South Asia would be stabilizing.[74] As long as the attacks are not too outrageous, India can be deterred from striking back by the fear that the resulting war might escalate into nuclear combat. The 1999 attacks in Kargil, the 2002 attack on the Indian parliament, and the 2008 attack on Mumbai are the most obvious examples.

Nuclear-armed North Korea has conducted similar provocative attacks on South Korea. In March 2010, North Korea torpedoed and sank the South Korea frigate Cheonan and in November 2010 it shelled the inhabited South Korean island of Yeonpyeong.

A nuclear-armed Iran could similarly conduct various provocative attacks in the Middle-East. Recent unrest in Bahrain could be a promising target for Iran since it could play on the disaffection that Bahrain's Shia majority has for its Sunni dominated government. Even Saudi Arabia could be a target as there are some in that country who would like to emulate the democratic uprisings occurring in other Arab countries. Destabilizing Saudi Arabia could also be a means of striking at the U.S., since even if Iran's effort were unsuccessful, the unrest would likely drive up oil prices, causing significant economic impact in the West.

[74] That nuclear weapons might exacerbate instability at the lower end of the conflict spectrum in South Asia was suggested as long ago as 1997. See: Ashley J. Tellis, "Stability in South Asia," RAND, 1997, p.32.

A SUMMARY OF THE KEY POINTS

By using batch recycling at the FEP and using its current stockpiles of 3.5% and 19.7% enriched uranium, Iran could produce the 20 kilograms of HEU required for a nuclear weapon in about two months from the time it decided to proceed. This is a dramatic reduction in the time that would have been required only a few years ago, as in the early part of 2008, the time required would have been two to four years. The time could shrink to a few weeks over the next few years as Iran continues to expand its centrifuge enrichment capacity and its stockpile of 19.7% enriched uranium. By the beginning of next year, Iran's stockpile of 3.5% enriched uranium will have grown large enough that Iran will be able to produce a second batch of 20 kilograms of HEU about two and one half months after its first 20 kilogram batch of HEU.

The purpose of IAEA safeguards is only to provide "timely warning." Since Iran has stopped compliance with the Additional Protocol as well as the modified Code 3.1, the IAEA has stated that it cannot "provide credible assurance" that Iran does not have a clandestine centrifuge enrichment plant which could be producing HEU for nuclear weapons even now.

The IAEA has not been willing to admit to the seriousness of the threat posed by Iran's centrifuge facilities and enriched uranium stockpiles that are under safeguards. As Iran has shrunk the time required for it to produce HEU by batch recycling at the FEP, the point has probably already been reached where the IAEA can no longer provide "timely warning" and therefore these facilities and materials can no longer be effectively safeguarded. This is an issue that applies to all centrifuge enrichment facilities of significant capacity, not only those in Iran. Unless this problem is addressed, Iran will be able to move closer and closer to a nuclear weapons capability until it essentially has nuclear weapons. All the while, Iran would not need to divert any material from safeguards until it was far too late for any counteraction to be taken.

If the IAEA were to sound the alarm about Iran's nuclear program, the ultimate response would be some sort of military action, but military action is rather unlikely. Ironically, Israel's strike on Syria in 2007 illustrates that it probably will not strike Iran. After ten years of war in Afghanistan and Iraq, the U.S. is too war-weary and financially exhausted to consider an invasion of Iran. The U.S. could try to undertake limited strikes against Iran's centrifuge enrichment program but isolated strikes would only delay the program and drive it further underground. Only a sustained campaign would likely be able to stop Iran's centrifuge program but this could easily lead to an unwanted long-term war with Iran. The U.S. does not seem to have any realistic military options for eliminating Iran's centrifuge enrichment program.

Iran is able to produce the non-nuclear components for a nuclear weapon now and need not wait until it produces HEU. It took the U.S. only 11 months to produce the implosion system for a nuclear weapon in 1944-1945 but Iran can likely produce an implosion system in a much shorter time interval. This is especially the case since the IAEA has said that Iran already "has sufficient information to be able to design and produce a workable implosion nuclear device based upon HEU as the fission fuel." In June 2011, Yukiya Amano, the director general of the IAEA said that the agency had received "further information related to possible past or current undisclosed nuclear-related activities that seem to point to the existence of possible military dimensions to Iran's nuclear program." He went on the say "The activities in Iran related to the possible military dimension seem to have been continued until quite recently."

It is difficult to consider the current nuclear developments in Iran as benign. Rather Iran does indeed have a nuclear weapons program. Its expanding centrifuge enrichment capacity, and stockpiles of 3.5% and 19.7% enriched uranium as well as its likely continuing research on the non-nuclear components of nuclear weapons is moving Iran ever closer to a nuclear weapons capability. Though Iran's leadership may have not yet specifically decided to develop nuclear weapons, the U.K., France, India and Nazi Germany at one time all had nuclear weapons programs before their governments had decided specifically to produce nuclear weapons. The U.K., France and India all went on to make such a decision and have produced nuclear weapons. This underscores the point that as Iran moves closer to having a nuclear weapons capability, it becomes increasing likely that Iran will make the decision to produce nuclear weapons.

Though Iran *could* produce the HEU required for a nuclear weapon in just two months that does not mean it *will* do so in the next two months. More likely, Iran will spend the next few years improving its position, by further shortening the time it will take it to move the last distance to a nuclear weapons capability. Iran will most likely continue to expand its centrifuge enrichment capacity and enlarge its stockpiles of 3.5% and 19.7% enriched uranium. At the same time, it could complete the production of the non-nuclear weapon components. By 2012 to 2015, this approach will allow Iran to become a de facto nuclear weapon state without ever violating its IAEA safeguards or detonating a nuclear weapon. Iran also has the option of building a clandestine centrifuge enrichment plant that produces HEU from natural uranium. Iran's noncompliance with its IAEA safeguards requirements means that such a clandestine plant could already be under construction or in operation.

By analogy with Pakistan, there are two key reasons to be seriously concerned about Iran gaining a nuclear weapons capability. First, Iran could either voluntarily or involuntarily lose control of one or more nuclear weapons, allowing them to be delivered covertly against targets such as Tel Aviv or New York. Second, Iran could feel that its nuclear weapons capability may protect it from major reprisals and therefore it might carry out various destabilizing attacks in the region on countries such as Bahrain or even Saudi Arabia.

Appendix 1

Prior Writings on Iran's Centrifuge Enrichment Program and Efforts to Acquire Nuclear Weapons

There are fourteen prior papers related to Iran's nuclear program of which I am the sole author.[75] This is a full list in chronological order.

"Iran's Centrifuge Enrichment Program as a Source of Fissile Material for Nuclear Weapons," April 8, 2008 http://128.177.28.81/files/20081017-Jones-IranEnrichment.pdf

"Iran's Centrifuge Enrichment Program as a Source of Fissile Material for Nuclear Weapons," August 17, 2009, Appendix added August 31, 2009 http://www.npolicy.org/article_file/20090817-Iran_Enrichment_Update_290111_0621.pdf

"Fueling the Tehran Research Reactor: Technical Considerations on the Risks and Benefits," October 12, 2009 http://www.npolicy.org/article_file/20091012-Jones_trr_0_290111_0524.pdf

"IAEA November 16, 2009 Update: Implications for Iran's Ability to Produce Fissile Material for Nuclear Weapons," November 17, 2009 http://www.npolicy.org/article_file/20091117-Jones_Iran_Enrichment_Update_310111_0443.pdf

"Iran's Increasing Progress towards a Nuclear Weapons Capability: Centrifuge Enrichment and the IAEA February 18, 2010 Update," February 23, 2010 http://128.177.28.81/files/20100223-Jones_Iran_Enrichment_Update.pdf

"When Could Iran Have the Bomb? An Analysis of Recent Statements That Iran is 3 to 5 Years Away," April 26, 2010 http://128.177.28.81/node/1255

"Iran Nears the Finish Line in its Quest to Acquire the Ability to Produce Fissile Material for Nuclear Weapons: Centrifuge Enrichment and the IAEA May 31, 2010 Update," June 2, 2010 http://npec.xykon-llc.com/files/20100602-Jones_Iran_Enrichment_Update.pdf

"Iran Achieves the Ability to Produce Fissile Material for Nuclear Weapons and Maintains Steady Enriched Uranium Production: Centrifuge Enrichment and the IAEA September 6, 2010 Update," September 9, 2010 http://www.npolicy.org/article_file/Iran_Achieves_the_Ability_to_Produce_Fissile_Material_for_Nuclear.pdf

[75] All of this work was performed either for the Bipartisan Policy Center and/or the Nonproliferation Policy Education Center. Though the author is also a part-time adjunct staff member at the RAND Corporation, none of this work was performed for RAND and RAND bears no responsibility for any of these papers or the analysis and views expressed in them.

"Iran's Rate of Enriched Uranium Production Continues to Increase: Centrifuge Enrichment and the IAEA November 23, 2010 Update," November 30, 2010 http://www.npolicy.org/article_file/Irans_Rate_of_Enriched_Uranium_Production.pdf

"An Analysis of Recent Israeli Statements Regarding When Iran Could Have the Bomb: Have the Israelis Given Up Trying to Stop an Iranian Nuclear Weapon?" January 13, 2011 http://128.177.28.81/node/1404

"The Pleasures Of Self-Deception: The Fiction That Cyber Attacks Have Slowed Iran's Drive for Nuclear Weapons," January 26, 2011 http://www.npolicy.org/article_file/The_Pleasures_of_Self_Deception_Fiction.pdf

"Cyber Attack, What Cyber Attack? Iran's Rate of Enriched Uranium Production Remains Steady: Centrifuge Enrichment and the IAEA February 25, 2011 Update," March 14, 2011 http://www.npolicy.org/article_file/What_Cyber_Attack.pdf

"Critique of IISS Estimates of the Time Required for Iran to Produce the HEU Metal Core Required for a Nuclear Weapon, Addendum: Time Required to Produce the Non-Nuclear Components Needed for a Nuclear Weapon," March 3, 2011, Revised April 6, 2011 http://www.npolicy.org/article_file/Critique_of_IISS_Estimates_with_Addendum.pdf

"Out of the Spotlight Iran's Rate of Enriched Uranium Production Continues to Increase: Centrifuge Enrichment and the IAEA May 24, 2011 Update," June 2, 2011 http://www.npolicy.org/article_file/Iran_Enrichment_Update-Greg_Jones.pdf

I have also coauthored an article with Henry Sokolski:

"Bombshell: Obama has run out of time to negotiate with Iran," *The New Republic*, December 7, 2010 http://www.tnr.com/article/79691/bombshell-iran-nuclear-bomb-uranium-negotiations-obama

Appendix 2

Basics of Uranium Isotope Separation

The purpose of this appendix is to provide a general overview of various concepts related to uranium isotope separation so as to make the text more understandable. For those who desire additional information, there are a number of more detailed sources.[76]

The majority of elements consist of two or more isotopes. These are atoms that have the same number of protons but differing numbers of neutrons. The different isotopes of an element all have approximately the same chemical properties but can have quite different nuclear properties. Natural uranium has two principal isotopes, U-235 and U-238. The isotope U-235 is the one that is desirable for processes involving nuclear fission reactions, including nuclear fuel and nuclear explosives. However, U-235 is only about 0.7% of natural uranium (usually taken to be 0.711 weight percent) with the rest being 99.3% U-238. For most purposes the percentage of U-235 must be increased (enriched). When uranium is referred to as being x% enriched, the x always refers to the fraction of U-235.

In any centrifuge enrichment plant, uranium of a certain enrichment is fed into the plant and two streams (product and tails) are withdrawn from it. The product stream consists of uranium with a higher enrichment than the feed and the tails stream consists of uranium with a lower enrichment than the feed. For example, to produce one kilogram of 3.5% enriched product requires 10 kilograms of natural uranium feed and also produces 9 kilogram of tails if the tails enrichment is 0.4%. (Conservation of mass requires that the sum of the product and tails always equals the feed).

The smallest unit of an isotope separation plant that effects some separation of the process material is called a separating unit, which in the case of Iran's enrichment effort is a centrifuge. The chemical form of the uranium fed to a centrifuge must have the physical characteristic of being gaseous at near room temperatures. The only uranium compound that has this property is uranium hexafluoride. The centrifuge separates an incoming feed stream of uranium hexafluoride into two outgoing streams: a product stream in which the uranium is enriched in U-235 compared to the feed and a tails stream which is somewhat depleted in U-235 compared to the feed. Since the flow through a single centrifuge is rather low, an enrichment plant consists of a number of centrifuges operating in parallel each being fed with feed with the same enrichment and producing product and tails with the same enrichment. This group of parallel-connected centrifuges is known as a stage. Since the degree of enrichment produced by a single stage is generally less than is desired for the product, an enrichment plant is composed of a

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[76] Manson Benedict, Thomas H. Pigford and Hans Wolfgang Levi, *Nuclear Chemical Engineering*, 2nd Edition, McGraw-Hill Book Company, New York, 1981; Stelio Villani, *Isotope Separation*, American Nuclear Society, 1976; Allan S. Krass, et al., *Uranium Enrichment and Nuclear Weapon Proliferation*, Stockholm International Peace Research Institute, Taylor & Francis Ltd, London 1983; and Karl Cohen, *The Theory of Isotope Separation as Applied to the Large-Scale Production of U-235*, McGraw-Hill Book Company, Inc. New York, 1951.

number of stages connected in series. Such a series-connected group of stages is known as a cascade.

The portion of the cascade between the feed point and the product end is known as the enriching section. Since uranium has significant economic value, stages are used to reduce the enrichment of the tails produced by the enrichment plant. These stages are known as the stripping section and are located between the feed point and the tails end. The use of a stripping section allows the amount of feed required to be significantly reduced.

The capacity of a separation element and an enrichment plant are measured in separative work units (SWU) per unit time. There is no simple explanation of what an SWU is but despite the term, it is not related to the physics concept of work. Rather it has units of mass (usually kilograms). The SWU needed to produce a given amount of uranium product can be calculated if the U-235 concentration in the product, feed and tails are known.[77]

When a cascade is operating at equilibrium, there is a steady increase in the uranium enrichment from the feed stage, through the enriching section, to the product stage. However, when the plant first starts operation, the plant is filled entirely with uranium having the enrichment of the feed. The plant must operate for a while to create the internal enrichment gradient in the plant so that the uranium product with desired enrichment can be produced. This time is the equilibrium time, which for many enrichment processes can be quite long but it is short for a centrifuge enrichment plant.

[77] Separative work calculators are available on the internet. See for example: http://www.wise-uranium.org/nfcue.html