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Recalibrating Tehran's Nuclear Breakout Capability II:

A Response to Mark Fitzpatrick's (IISS) critique of NPEC Calculations Regarding the Time Required for Iran to Produce a Weapon's Worth of HEU

Since 2008 I have written fifteen papers on Iran's centrifuge enrichment program describing how Iran is moving ever closer to a nuclear weapons capability. Recently, several analysts who claim Iran could not possibly acquire sufficient weapons-grade uranium to make its first bomb in less than 6 to 24 months, have taken strong exception to my analysis. My calculations indicate that if Tehran chose to, it could acquire this material in as little as 2 months using its declared enrichment plant at Natanz.[2] I have already reviewed a critique by David Albright of Institute for Science and International Security which maintained that Iran would need six months to acquire enough highly enriched uranium (HEU) to produce a nuclear weapon. My review showed that Albright has not documented his six month claim and that his criticisms of my calculations were in many cases irrelevant and that the rest would produce only minor changes to them.

Recently Mark Fitzpatrick of the International Institute of Strategic Studies (IISS) gave a talk which has been written up as an article published on the Arms Control Association's website.[3] He has said that my calculations: "string together a series of improbable worst-case assumptions" and that my calculation that Iran could produce the HEU for a nuclear weapon in just two months should it decide to do so, "borders on the irresponsible." Instead his estimate is that Iran "theoretically could go for broke and obtain a nuclear weapon in less than two years…"

Fitzpatrick's comments are based on an IISS report published in February 2011.[4] This report estimated that Iran could produce enough HEU for a nuclear weapon in one to two years and that their preferred estimate was two years. I published a critique of this IISS paper and found that IISS used a series of dubious assumptions in their calculations.[5] Naturally I was interested in

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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] Gregory S. Jones, "An In-Depth Examination of Iran's Centrifuge Enrichment Program and Its Efforts to Acquire Nuclear Weapons", August 9, 2011, http://npolicy.org/article.php?aid=1092&rt=&key=Greg%20Jones&sec=article & Greg Jones, "No More Hypotheticals: Iran Already Is A Nuclear State," *The New Republic"*, September 9, 2011, http://www.tnr.com/article/environment-and-energy/94715/jones-nuclear-iran-ahmadinejad

[3] Mark Fitzpatrick, "Assessing Iran's Nuclear Program Without Exaggeration or Complacency," Iran Nuclear Brief, The Arms Control Association, October 3, 2011. Fitzpatrick's original talk was on September 19, 2011.

[4] *Iran's Nuclear, Chemical and Biological Capabilities, A net assessment*, an IISS strategic dossier, The International Institute for Strategic Studies, London, 2011.

[5] 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

how Fitzpatrick would readjust the IISS estimates in light of my critique but instead he has ignored my criticisms. Rather Fitzpatrick repeatedly misrepresents my views. In addition he continues to use many of the same dubious assumptions that were in the original IISS paper.

Fitzpatrick starts by saying:

> "We can have high confidence that Iran does not today have a nuclear weapon and that it won't have one tomorrow or next week or next month or a year from now. To claim otherwise on the basis of an amalgamation of worst-case assumptions borders on the irresponsible."

However, I do not claim that Iran will overtly acquire nuclear weapons any time soon—a matter I consider to be highly uncertain. The issue is Iran's steady shortening of the time required for it to acquire a nuclear weapon should it desire to do so, all the while staying within IAEA safeguards. In 2008, I estimated that it might take Iran two to four years to produce the HEU needed for a nuclear weapon, but by June 2011, this time had shrunk to only two months. Further it appears that by the later part of 2012, this time may shrink to only two weeks. But I have nowhere said that I soon expect Iran to actually acquire nuclear weapons. As I said in my recent *New Republic* article:

> "That is not to say that I expect Iran to divert nuclear material from IAEA safeguards anytime soon. After all, why should it? It can continue to move ever closer to the HEU required for a nuclear weapon with the blessing of the IAEA. Iran would only need to divert nuclear material from safeguards when it would want to test or use a nuclear weapon. Recall that the U.S. was unable to certify that Pakistan did not have nuclear weapons in 1990, but it was only in 1998 that it actually tested a bomb. Similarly, though it could be many years before Iran becomes an overt nuclear power, it needs to be treated as a de facto nuclear power simply by virtue of being so close to having a nuclear weapon."

Though Fitzpatrick has referenced my *New Republic* article, he seems not to have read it. I find it rather ironic that Fitzpatrick should say that I am irresponsible for holding a view that in fact I do not hold but instead involves Fitzpatrick misrepresenting my views.

The bulk of Fitzpatrick's criticisms of my calculations involve his claim that I "string together a series of improbable worst-case assumptions". There are five of these that he feels are "questionable" and discusses in detail.

The first assumption that Fitzpatrick feels is "questionable" relates to how Iran would use its existing large scale centrifuge enrichment plant (the Fuel Enrichment Plant [FEP] at Natanz) to produce HEU. As currently setup, this plant takes natural uranium (0.7% U-235) and enriches it is 3.5% U-235. However, to produce a nuclear weapon, this uranium must be further enriched until it is 80-90% U-235. There are two ways to do this at the FEP. The plant can be repiped so that 3.5% enriched uranium can be continuously enriched to the 80-90% level or batch recycling

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Nuclear Weapon," March 3, 2011, Revised April 6, 2011.
http://www.npolicy.org/article_file/Critique_of_IISS_Estimates_with_Addendum.pdf

can be used which requires no alteration of the current plant but rather the enriched uranium is recycled though the plant in batches until it reaches the required enrichment. The IISS assumes that Iran would repipe the FEP, whereas I assume that Iran would use batch recycling.

The IISS prefers the repiping of the FEP option because this procedure would allow Iran to construct an enrichment plant configuration similar to what Pakistan was attempting to sell to Libya. The IISS assumes that this configuration is what Pakistan uses at its own enrichment plants (though there is no direct evidence of this) and Fitzpatrick considers the repiping option to be “tried and true”.

However, the IISS admits that for Iran, any effort to violate safeguards to produce HEU would create a situation where “time is of the essence.”[6] Yet the IISS calculates that by repiping the enrichment plant it would take Iran 84 weeks (19 months) to produce enough HEU for a nuclear weapon whereas using batch recycling would require only 26 weeks (6 months).[7] Fitzpatrick’s view that because the time required for batch recycling might be uncertain, Iran would choose to repipe the FEP and be certain to take over three times as long is unrealistic. In a situation where time is of the essence, assuming that Iran would choose the much faster batch recycling method is hardly an “improbable worst case.”

Fitzpatrick claims that batch recycling has “never been used in practice” but this is false. Not only has it been used in practice but it is the Iranians who have used it at its pilot fuel enrichment plant (PFEP) where one of its standard enrichment cascades (designed to produce 3.5% enriched uranium from natural uranium) was installed. On February 9, 2010 Iran began feeding this cascade 3.5% enriched uranium and only two days later Iran was able to produce 19.7% enriched uranium, showing that not only is batch recycling feasible but that the Iranians encountered no problems using it. Furthermore, all of this was discussed in my critique of the IISS’s February 2011 report and is therefore known to Fitzpatrick. Yet he continues to make the false claim that batch recycling is untested.

The second assumption that Fitzpatrick feels is “questionable” is related to his claim that I assume in my calculations that Iran can produce enough HEU for a nuclear weapon before this activity could be detected by the IAEA. But again Fitzpatrick attributes to me an assumption that in fact I do not make. Certainly it is true that as Iran continues to shorten the time needed to produce a nuclear weapon, a point will be reached where it is unlikely that the IAEA will detect Iran’s actions before Iran can produce a nuclear weapon. However, my argument does not depend on this fact. Rather my concern is with the inadequacies of IAEA safeguards and what it is that they are intended to do.

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[6] *Iran’s Nuclear, Chemical and Biological Capabilities, A net assessment*, an IISS strategic dossier, The International Institute for Strategic Studies, London, 2011, p.70.

[7] The difference between the IISS’s estimate of 6 months for the production of a weapon’s worth of HEU by batch recycling and mine own estimate of 2 months is the result of three factors. First, the IISS uses 3,500 SWU per year as the separative capacity of the FEP instead of its current capacity of 4,300-4,600 SWU per year. Second, the IISS assumes that for a first nuclear weapon, Iran would have to produce 37.5 kilograms of HEU whereas I assume only 20 kilograms of HEU (this issue will be discussed in more detail later in this paper). Third, the IISS does not take into account Iran’s stockpile of 19.7% enriched uranium.

The purpose of IAEA safeguards is to provide "timely detection of diversion of significant quantities of nuclear material." The detection is "timely" only if it occurs soon enough so that not only does it occur before a country has produced a nuclear weapon but with early enough for effective counteraction to be taken. But what if a country moves ever closer to a nuclear weapons capability but does not divert the nuclear material? The IAEA has been unwilling to admit that there are some materials (such as separated HEU and plutonium) and activities (such as centrifuge enrichment) that it cannot effectively safeguard (in the timely detection sense) but instead it can only monitor them. The IAEA has drawn no boundary lines where it will say that it can no longer effectively safeguard a country's nuclear program even if no diversion takes place.

Seventy nine percent of my current two month estimate for Iran to produce a weapon's worth of HEU at the FEP by batch recycling consists of enriching 3.5% uranium to 19.7% uranium. Yet if Iran were to start this activity, it could hardly be considered to be a violation of its safeguards since Iran has already been producing 19.7% enriched uranium from 3.5% enriched uranium at the PFEP since February 2010. Yet with a large enough stockpile of 19.7% enriched uranium, Iran would need only two additional weeks to produce a weapon's worth of HEU by batch recycling at the FEP.

Further Iran need not violate its safeguards (by diverting nuclear material) to produce HEU at the FEP. After all, other non-weapon states have research reactors that utilize HEU, so if Iran says that it wants to produce HEU at the FEP under safeguards to use in a research reactor, who is the IAEA to say no? Iran could then produce large quantities of HEU in the form of uranium hexafluoride at the FEP.

Uranium hexafluoride can be converted into uranium metal spheres suitable for direct use in a nuclear weapon in only about a week (this will be discussed in more detail below). But even this activity need not violate safeguards if no diversion takes place. The IAEA has in the past safeguarded large quantities of HEU in metallic form that non-weapon states have used in research reactors. If Iran said that it needs these HEU metal spheres for nuclear research (perhaps to perform criticality experiments), should it be denied these fruits of "peaceful" nuclear energy? Yet these uranium metal spheres could be inserted into nuclear weapons and detonated in a matter of hours.

So unless the IAEA clearly states what it can effectively safeguard and what it cannot, countries can get very close to a nuclear weapons capability without ever having to divert nuclear material. By being permitted to produce 19.7% enriched uranium and have a significant centrifuge enrichment capacity, by next year Iran will be able to move to within just two weeks of being able to produce the HEU for a nuclear weapon.

The IISS itself has considered Iran's production of 19.7% enriched uranium an ominous development. Iran is currently using two interconnected cascades at the PFEP to produce between 2.5 and 3.2 kilograms of 19.7% enriched uranium per month. This is a relatively low production rate and it would take Iran about four to five years to produce enough 19.7% enriched uranium to batch recycle to produce the HEU for a nuclear weapon, though since this process has been going on since February 2010 about one and two thirds years of this four to five year process has already elapsed. The IISS seems willing to accept Iran's current rate of 19.7% enriched uranium production but in its February 2011 report it said: "…any attempt by Iran to produce 20%-enriched uranium using more than the two cascades now devoted to this purpose would be suspicious. It would probably spark an international crisis because it would bring Iran significantly closer to weapons-usable HEU with so little justification." (p.74)

In June of 2011 Iran announced that it was going to triple its production of 19.7% enriched uranium by installing four additional cascades at the Fordow Fuel Enrichment Plant near Qom. The latest IAEA safeguards update (September 2011) indicate that in August, Iran was already installing these cascades. Recent press reports have said that Iran will soon transfer uranium hexafluoride to this site, indicating that production may begin shortly. Though in February the IISS said that such a development would bring Iran "significantly closer" to the HEU for a nuclear weapon, Fitzpatrick has barely changed his estimate of when Iran might be able to obtain the HEU for a nuclear weapon (from "two years" to "less than two years"). Fitzpatrick certainly has not suggested that there should be an international crisis over this matter and this whole episode illustrates a lack of seriousness on the part of Fitzpatrick and the IISS.

The third assumption that Fitzpatrick claims is "questionable" relates to what he says is the false belief that a bomb's worth of HEU is a static number. Though from his current paper it is a little hard to figure out what he is arguing, the February 2011 IISS paper makes his point clearer. Basically he argues that though a finished nuclear weapon might only need 20 kilograms of HEU, during the production process to produce the weapon, especially the first time that a country produces a nuclear weapon, HEU will be lost (though not necessarily permanently) to what he calls "wastage." The February 2011 IISS report makes it clear that they believe that 37.5 kilograms of HEU will need to be produced for the first weapon. This is nearly double (88% increase) over the 20 kilograms I use in my calculations. The IISS estimated their 37.5 kilogram requirement by taking the IAEA "significant quantity" for HEU of 25 kilograms and multiplied by 1.5.

However, as I pointed out in my critique of the February 2011 IISS report, the IAEA makes clear that it has already considered "unavoidable losses due to conversion and manufacturing processes." In other words the IAEA had already included a wastage factor and therefore by adding an additional such factor the IISS is double counting. I had pointed out this error in my critique of the IISS's February paper but again Fitzpatrick has not made any correction to his estimate.

However, Fitzpatrick's claim that large extra amounts of HEU would be needed to produce a nuclear weapon runs counter to the historical experience. As I have shown (see appendix), the U.S. experience in preparing the Hiroshima nuclear weapon demonstrates that despite this being the first time in history that metallic HEU was produced and handled, the wastage involved was very small—likely no more than a few percent. If the U.S. had really needed to produce 88% more HEU than was actually needed for the weapon, then the Hiroshima nuclear weapon would not have been ready until October 1945, instead of when it actually was at the end of July. Since this aspect of my analysis is firmly based on historical experience, it is hard to see why Fitzpatrick considers it to be an "improbable worst-case."

The fourth assumption that Fitzpatrick claims is "questionable" is that once Iran has sufficient HEU, it could quickly produce a nuclear weapon. Rather he (and the IISS) assumes that it would take Iran the astoundingly lengthy period of six months to produce a weapon after the completion of the production of the HEU.

The original IISS report was ambiguous as to why the production of a completed weapon would take so long. In places the IISS report implied that this six month period would be taken up converting the HEU in the form of uranium hexafluoride into the metal sphere needed for a weapon and in other places it implied that the production of a nuclear weapon was a sequential process where first the HEU is produced and only then can the non-nuclear components manufactured. In my critique of this report, I pointed out that most if not all of the current nuclear weapon states had produced the fissile material and the non-nuclear components for their nuclear weapons in parallel and not in sequence.[8] In his current paper, Fitzpatrick attempts to argue both these points simultaneously. He says that Iran could carry out the weaponization steps in parallel to producing the HEU but though "in theory, this may be correct, but probably not for a country that's never done it before". He goes on to say that the production of the HEU metal sphere, plus "the assembly of the bomb" and what he calls "all the other steps needed to produce a workable nuclear weapon" (he does not specify what these "other steps" might be) would take six months.

However, it is well established historical fact, not just theory, that a state can develop the non-nuclear components for its first nuclear weapon in parallel with the production of the fissile material needed for the weapon. This fact has been known since the beginning of the nuclear age. 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."[9] [Emphasis added]

A clear indication that it is possible to complete the "ordnance part" of a nuclear weapon without having the fissile material first can be found in the U.S. experience in World War II. The non-nuclear components of the Hiroshima nuclear weapon were on the cruiser *Indianapolis* and sailing across the Pacific Ocean while some of the HEU components for the weapon were still being manufactured (see appendix).

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[8] 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, pp.4-6 & pp.8-10. http://www.npolicy.org/article_file/Critique_of_IISS_Estimates_with_Addendum.pdf

[9] 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.

As far as the time required to produce the HEU metal components for the Hiroshima weapon, the U.S. did not finish enriching the uranium needed for the weapon until about July 15, 1945. Yet the final components were already fully manufactured by July 24. Though Fitzpatrick implies that it might take a long time to assemble the nuclear weapon, in fact these final HEU components were flown to Tinian, arriving July 29 and the weapon was ready for use by July 31.

This history is hardly compatible with the IISS's six month estimate. Though the Hiroshima weapon was a gun type (see appendix), the procedure would even be simpler today for Iran using an implosion type weapon. Early U.S. implosion nuclear weapons (and based on reports, current Pakistani weapons) were designed so that the nuclear core can be quickly inserted into the nuclear assembly. For at least some early U.S. nuclear weapons this insertion took place in-flight, indicating that the whole procedure took no more than a few hours. Indeed much of the time needed to prepare early U.S. nuclear weapons involve mundane items such as batteries, things that have been greatly improved in the last 66 years.

The IAEA has also considered this issue and established "conversion times" which are "the time required to convert different forms of nuclear material to the metallic components of a nuclear device." In the case of HEU in the form of uranium hexafluoride, the IAEA estimates the conversion time to be about one week. This estimate is quite similar to those derived from the U.S. World War II experience, whereas the IISS's six month estimate would imply that the U.S. could not have had the Hiroshima weapon ready before January 1946. I raised all of these issues in my critique of the February 2011 IISS paper but again Fitzpatrick's assessment has not changed. Instead he refers to historical events as being theoretical and claims that these events as well as the assessment of the IAEA are "improbable worst-case assumptions."

The fifth assumption that Fitzpatrick claims is "questionable" is that Iran "would go for broke to produce just one weapon." But again I do not make this assumption. As was discussed above, I think it likely that it will be many years before Iran would want to "go for broke" and overtly produce nuclear weapons. By that time Iran would be in a position a number of nuclear weapons. I have already estimated that by early 2012, Iran will have accumulated enough enriched uranium to be able to produce two nuclear weapons by batch recycling. I also recently published an estimate that if Iran has a small clandestine enrichment plant, then it could combine the output of this plant with the uranium produced by the batch recycling of its current enriched uranium stockpiles at the FEP to produce three nuclear weapons.[10] So already, Iran's continued growth of its enriched uranium stockpiles means that Iran is in a position to produce more than just one nuclear weapon.

My calculations of how quickly Iran could produce enough HEU for a nuclear weapon is an important metric as to how close Iran is to being able to produce nuclear weapons. This metric has important implications for the adequacy of IAEA safeguards. The metric also has implications for the likelihood that Iran will make the final decision to actually produce nuclear weapons, since the closer Iran is to a nuclear weapon, the easier it will be for Iran to take the

[10] Gregory S. Jones, "Recalibrating Tehran's Nuclear Breakout Capability: A Response to ISIS's Critique of NPEC Calculations Regarding the Time Required for Iran to Produce a Weapon's Worth of HEU," October 19, 2011, http://npolicy.org/article.php?aid=1105&rid=4

final decision to overtly produce nuclear weapons. However, this metric was never intended to be a prediction of how Iran might actually acquire nuclear weapons.

In sum, I have calculated that Iran could produce the HEU for a nuclear weapon in just two months *should it decide to do so*. This calculation was never intended to be a prediction about when Iran might actually become an overt nuclear power. I consider it likely that Iran will not be an overt nuclear power for many years and have been very clear about all of this in my prior writings.[11] For Fitzpatrick to imply otherwise and then use this as the basis to say that my work "borders on the irresponsible" is rather ironic.

Fitzpatrick claims that my work strings together five "improbable worst-case assumptions." However, two of his five assumptions are not ones that I make. Of the other three, none of them are improbable or worst-case.

Fitzpatrick says that Iran would prefer to repipe the FEP to produce HEU rather than use batch recycling. However, Fitzpatrick realizes that if Iran were to violate its IAEA safeguards, time would be of the essence. Yet repiping the FEP would take over three times as long as batch recycling. Further his claim that batch recycling is untested is false since Iran has already used batch recycling to produce 19.7% enriched uranium at the PFEP.

Fitzpatrick makes two other assumptions: 1) that a first time nuclear weapon state would process its HEU so inefficiently that it would need to produce nearly double the amount of HEU required to account for "wastage" and 2) that the processing of the HEU and the mating of it with the weapon would be so slow that it would take six months after producing the HEU to complete the finished weapon. Both of these assumptions are contradicted by historical experience and in particular the U.S. experience in World War II producing the Hiroshima weapon. The "wastage" in the processing of the HEU for this weapon was no more than a few percent. Nor did it take much time to process the HEU. The enrichment of the HEU was not finished until about July 15, yet the metal HEU components for the weapon were finished on July 24. These HEU components were delivered to Tinian on July 29 and it only took two days to mate these components to the rest of the weapon which was then ready for use.

Fitzpatrick's (and the IISS's) February 2011 estimate of two years has proven to be remarkably resistant to change in the light of contrary information. The IISS used a separative capacity of 3,500 SWU per year, whereas the current separative capacity is 4,300-4,600 SWU per year—a 25% increase. In February the IISS ignored Iran's stockpile of 19.7% enriched uranium whereas as of August 2011, Iran had a stockpile of 48 kilograms. In February the IISS had recognized that if Iran were to significantly increase its rate of production of 19.7% enriched uranium, it would bring Iran "significantly closer" to the HEU for a nuclear weapon. Yet Fitzpatrick has chosen to ignore Iran's concrete steps to triple its production of 19.7% enriched uranium. In light of my critique of the IISS's February report, Fitzpatrick has retained false information in his estimate (such as his continued claim that batch recycling is untested) and to dismiss historical

[11] Greg Jones, "No More Hypotheticals: Iran Already Is A Nuclear State," *The New Republic*", September 9, 2011, http://www.tnr.com/article/environment-and-energy/94715/jones-nuclear-iran-ahmadinejad & Gregory S. Jones, "An In-Depth Examination of Iran's Centrifuge Enrichment Program and Its Efforts to Acquire Nuclear Weapons", August 9, 2011, pp.29-31, http://npolicy.org/article.php?aid=1092&rt=&key=Greg%20Jones&sec=article

experience as being merely theoretical. Instead of making the marginal change in his estimate from two years to his current "theoretically…less than two years", Fitzpatrick and the IISS need to make a serious estimate taking into account the current realities regarding Iran's nuclear program.

Appendix

U.S. Production of the Hiroshima Nuclear Weapon
Implications for an Iranian Nuclear Weapon

During World War II the U.S. conducted an all-out effort to produce nuclear weapons. It produced both plutonium and HEU to use as the fissile material in such weapons. It was recognized that the most efficient way to detonate these fissile materials would be to construct implosion type nuclear weapons. In such weapons the fissile material is surrounded by explosives which are then detonated to compress the fissile material into a supercritical mass.

However, in 1944 no one had ever constructed such a device and instead it was planned to use gun-type nuclear weapons. In such weapons a subcritical projectile of fissile material is fired into a subcritical target of fissile material, producing supercritical mass leading to a nuclear explosion. Such weapons require multiple critical masses of fissile material and utilize this material inefficiently but they had the advantage of relying on well-established artillery technology. However, the discovery that plutonium produces a high number of spontaneous fission neutrons meant that gun-type plutonium-based nuclear weapons would produce only very low yields. Instead plutonium-based implosion nuclear weapons were successfully developed and used in World War II. However, due to the uncertainties in producing implosion weapons, it was decided to continue to develop HEU-based gun-type nuclear weapons.

As part of the Manhattan Project, the U.S. used several different methods to produce HEU. This was the first time that the large scale production of HEU had been attempted and there were various technical difficulties. Though significant HEU production began in the summer of 1944, the production rate was low—only about 1 kilogram of U-235 per month.[12] In the first part of 1945, the rate significantly increased to 5 to 7 kilograms of U-235 per month.

Since large amounts of HEU had never existed before, as the material was produced it was distributed to various groups so that its properties could be studied. But starting on June 4, 1945, this HEU was collected and began to be fashioned into the components needed for the weapon.[13] By early July, all of the weapon's non-nuclear components as well as the HEU projectile were completed. These parts were transported to San Francisco and loaded onto the cruiser *Indianapolis*. After the successful nuclear test at Alamogordo on July 16, the cruiser made a high-speed run to the island of Tinian. It arrived on July 26.

But there was not yet enough HEU to make the weapon's HEU target and production was continuing. On June 27 workers at the Y-12 facility were exhorted to increase their efforts. Production records imply that it was only July 15 before sufficient HEU was received at Los

[12] The HEU production is reported as the number of kilograms of U-235 produced per month. The enrichment of this material was variable, ranging from 63% to 89%. See: David Hawkins, *Manhattan District History, Project Y, The Los Alamos Project*, LAMS-2532, Volume I, report written in 1946, report distributed in December 1961, p.308.

[13] Richard G. Hewlett and Oscar E. Anderson, *The New World,* A History of the Atomic Energy Commission, Volume I, 1939/1946, WASH 1214, Atomic Energy Commission, 1962, pp. 374-375.

Alamos.[14] Only nine days later on July 24, the HEU target was ready.[15] This component was transported by air to Tinian and arrived during the night of July 28-29. By July 31 the weapon was ready but due to poor weather, it was not dropped on Hiroshima until August 6.

This history has implications for Iran's production of a nuclear weapon and provides insight into not only the question of the magnitude of HEU manufacturing "wastage" but also how quickly after the production of the HEU, a fully finished nuclear weapon can be produced.

After the HEU has been produced by the enrichment process, it must be converted into metal and then shaped into the proper form for a nuclear weapon. For the Hiroshima weapon this shape was cylindrical and for an implosion-type weapon, it would be spherical. As with any manufacturing process, not all of the starting material winds up in the final product. Fitzpatrick realizes that since HEU is more valuable than gold, the manufacturing waste would be recycled and the "lost" material recovered. However, Fitzpatrick believes that the material cannot be recovered in time for use in the first nuclear weapon, though he is not specific as to how long this recovery process might take. He (and the IISS) assumes that the wastage is very large, requiring 1.88 times the amount of the final HEU mass in the weapon to be produced by the enrichment process. Albright has also given estimates for the magnitude of wastage but his estimates are much lower than Fitzpatrick's, amounting to only 10-20%.[16]

From the U.S. experience in World War II we can see that even Albright's estimates are too high. Approximately 50 kilograms of U-235 were used in the Hiroshima nuclear weapon but according to the production records, only 50 kilograms of U-235 had been produced by July 15, 1945. Therefore the magnitude of the wastage in this case was minimal, and it is unlikely that it exceeded more than a few percent. This result demonstrates that the U.S. was able to recycle the manufacturing waste quickly enough so that the recovered material could be used in the Hiroshima weapon.

This same U.S. experience also shows that once the enrichment process has produced the HEU it can be quickly converted into HEU metal, machined to the proper shape and the weapon made ready for use in a short time. Enough HEU for the Hiroshima weapon was not produced until July 15, yet the HEU metal components were completed only nine days later. Once these components arrived on Tinian, it took only two days until the Hiroshima weapon was operational.

From the literature it is possible to gain hints as to how the quick and efficient production of a nuclear weapon is possible. The Chinese have indicated that before the actual machining of their

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[14] A total of 50 kilograms of U-235 had been produced by July 15, 1945. The amount and enrichment of HEU used in the Hiroshima weapon remains classified (though based on the production data, the enrichment had to be less than 89%). However the South Africans produced HEU nuclear weapons of the gun-type that had a yield of 14 kt ± 4 kt which is similar to that of the Hiroshima weapon (16 kt ± 2 kt). The South African weapon used 55 kilograms of 90% enriched HEU which contains 49.5 kilograms of U-235. See: David Albright, "South Africa and the Affordable Bomb", *Bulletin of the Atomic Scientists*, July/August 1994, pp.37-47.

[15] David Hawkins, *Manhattan District History, Project Y, The Los Alamos Project*, LAMS-2532, Volume I, report written in 1946, report distributed in December 1961, p. 253.

[16] David Albright, Christina Walrond, "Iran's Gas Centrifuge Program: Taking Stock," Institute for Science and International Security, February 11, 2010, p.16.

first sphere of HEU took place, they had conducted simulations and practice exercises for six months prior.[17] As early as December 1944, the U.S. had confirmed the basic principles of a gun-type nuclear weapon by conducting firings using natural uranium as a stand-in for HEU since they has the same mechanical properties.[18] Since natural uranium has the same chemical properties as does HEU, it would also make a good stand-in for practicing the production of uranium metal from uranium hexafluoride.

[17] John Wilson Lewis and Xue Litai, *China Builds the Bomb*, Stanford University Press, 1988, p.167.
[18] Richard G. Hewlett and Oscar E. Anderson, *The New World*, A History of the Atomic Energy Commission, Volume I, 1939/1946, WASH 1214, Atomic Energy Commission, 1962, p.312.

Questioning worst-case analyses of Iran's nuclear program

Mark Fitzpatrick in response to Gregory Jones

In my September 19, 2011 presentation in Washingtonhosted by the Arms Control Association (ACA) and my follow-up ACA brief[19], I questioned five assumptions behind analyses that string together worst-case assumptions to claim that Iran could produce a nuclear weapon in a very short amount of time. I was reacting in partto an article by Greg Jones in the *New Republic*, the headline of which claimed "...Iran Already is a Nuclear State." Authors are not always responsible for their headlines, but the editors must have felt this was a fair approximation of the claim in the article that: "The international community has no choice but to already treat the Islamic Republic as a de facto nuclear state." Claims like this can too easily fan agitation for war. My critique, as noted in the first footnote of the ACA brief[20], was in regard to various claims that relied upon Mr Jones' work. I realize that he did not predict Iran "would" have a nuclear weapon anytime soon. He argues that they "could" have one in two months. I dispute that the timeline is this short.

The first reason is that the batch recycling method of uranium enrichment that Jones uses in his calculations has never been used before to produce a nuclear weapon, so far as is known. Suggesting that Iran would go for broke using an untried system is therefore an improbable worst-case assumption. Jones notes correctly that Iran has succeeded in producing 19.75% enriched uranium with a cascade designed to produce 3.5% enrichment, similar to batch recycling. But as the IISS dossier warned and as others have noted,[21] the two-step batch recyclingprocess may not work for enrichment at the weapons-grade level of 90%.

The second questionable assumption is that Iran would be able to produce enough HEU before it was caught. I acknowledge that Jones' main argument is with regard to what IAEA safeguards are intended to do. I share his concern that Iran is getting closer to HEU production with its growing stockpile of 19.75% enriched product.But in his *New Republic* he did make the assumption that I questioned, when he wrote: "if the time required for Iran to produce HEU shrinks to about four weeks by the end of next year, as now seems inevitable, it's clear that timely detection by the IAEA will basically be impossible."In my ACA article I was too cautious when I said the average window of time between IAEA inspections is about

[19] Mark Fitzpatrick, "Assessing Iran's Nuclear Program Without Exaggeration or Complacency," Iran Nuclear Brief," The Arms Control Association, October 3, 2011.

[20] The footnote read: 'See "The undimmed danger of Iran's nuclear program," *Washington Post*, September 6 2011; Greg Jones "No More Hypotheticals: Iran Already is a Nuclear State," *New Republic*, September 9, 2011; and " Iran's Nuclear Program Status and Breakout Timing" staff paper of the Bipartisan Policy Center, September 2022, all of which draw from an analysis by Greg Jones produced for the Nonproliferation Policy Education Center on August 9, 2011.'

[21]David Albright, Paul Brannan, and Christina Walrond, **"**Critique of a Recent Breakout Estimate at the Natanz Fuel Enrichment Plant (FEP)", Institute for Science and International Security, September 20, 2011.

one month. Actually, it is half this time: the IAEA conducts at least 24 inspections at year of the Natanz enrichment plant, 12 scheduled and 12 unscheduled.[22]

The third questionable assumption concerns the static amount of enrichment work that is assessed to be required for a nuclear weapon. Jones is not the only one to fail to acknowledge the different timeline necessary for the first weapon and the timeline for subsequent weapons. The IISS Strategic Dossier on Iran published earlier this year[23]explained this difference. My ACA article put quotations around the word "wastage" because most of the material that is unused for the first bomb can be recovered for production of the second bomb. This is also explained in the IISS dossier. These temporary losses differ from the unavoidable losses that the IAEA factors into its calculation of a significant quantity. One 50% temporary lossfor the first weapon's worth of HEU occurs during the enrichment process as tails from each stage are collected in containers[24] before they are re-fed into the unit at a different stage. During the production of the first bomb's worth of weapons-grade HEU, a large amount of the original feed material is held up in the tails containers at intermediate levels of enrichment. More feed, and therefore time, is thus required for the first weapon. Analogous temporary losses occur during the metal conversion, casting and machining stage. The two 50% adjustment factors for temporary losses used in the IISS dossier reflect the judgment of government experts with experience in weapons manufacture. I acknowledge that some historical experience elsewhere indicates the loss at the metal conversion, casting and machining stage can be less than 50%. Jones usefully sheds light on the US experience in preparing the Hiroshima nuclear weapon.

The fourth questionable assumption is that the timeline for producing HEU is all that effectively matters because the gaseous HEU can be quickly converted to metal and made into a weapon. The IISS strategic dossier assessed that a minimum of six months is necessary for the weaponization process. Jones mischaracterizes the IISS dossier as implying that this six month period would be taken up solely in converting the highly enriched UF6 into a metal sphere. In fact, the dossier said:

> "fashioning the actual weapon is a complicated task. The steps include the reconversion of gasified HEU into metal; the shaping of the uranium metal into pits; the design of a weapon small enough to fit onto the warhead of a delivery vehicle; the fashioning of a nuclear triggering device; and, in the case of implosion devices, the production and fitting of the spherical explosive lenses and reflector. How long these steps take would depend, among other things, on how far Iran has progressed in weapons-design work to date and on how much foreign assistance it has received."

The IISS dossier cited three sources to support the six-month assumption.[25]The dossier also acknowledged that the US was able to produce a weapon more quickly. As noted in the dossier, however, "the Manhattan Project enjoyed the industrial might of a superpower along

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[22]IvankaBarzashka and Ivan Oelrich, "Increased Safeguards at Natanz: What Does It All Mean?" FAS Strategic Security Blog, August28, 2007.

[23]International Institute for Strategic Studies, *Iran's Nuclear, Chemical and Biological Capabilities: A net assessment* (London: IISS, 2011), pp. 69-72.

[24] My ACA article and page 72 of the IISS dossier erred in using the word "cold traps" for these tails containers, where the material solidifies through cooling.

[25]EastWest Institute, "Iran's Nuclear and Missile Potential: A Joint Threat Assessment by U.S. and RussianTechnical Experts," May 2009, p. 5; Robert Harney, Gerald Brown et al, "Anatomy of a Projectto Produce a First Nuclear Weapon,"*Science and Global Security*, vol. 14, 2006; and Center for American Progress, "Speech of CIA Director George Tenet," February 5, 2004.

with many of the best European minds."[26] Iran has a much smaller number of experts, and has lost some of them to defection and assassination. Moreover, the world's leading intelligence agencies are intent on finding and exposing any evidence of on-going work on weaponization. Iran thus has to be cautious about how it conducts such work. Under these circumstances, six months is a reasonable estimate for the time from HEU production to weaponization.

The fifth questionable assumption may be the most important: that Iran would go for broke just to produce one weapon. I acknowledge that Jones himself does not claim that Iran would rush to produce one weapon. Howeverarticles such as the one in the *New Republic*with its breathless headline do give readers reason to believe this. A focus of attention on how long it would take for Iran to produce just one weapon overemphasizes a highly unlikely scenario. It is the wrong question.

[26]International Institute for Strategic Studies, *Iran's Nuclear, Chemical and Biological Capabilities: A net assessment*, p. 84.