Technical Aspects of the Proposed Iran Deal Barring the Acquisition of HEU or Pu for a Nuclear Weapon

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Background

In the 1970s, the United States government was on excellent political and commercial terms with the Shah of Iran, Mohammad Reza Pahlavi. Indeed, as I recall, Donald Rumsfeld, on behalf of The White House, took the lead in offering Iran a full commercial nuclear power sector, including 20 one-GWe-class nuclear reactors, together with enrichment and reprocessing facilities—the “full fuel cycle.”

All this changed with the Islamic Revolution in Iran, February 11, 1979, the fall of the Shah, and the taking of 66 U.S. hostages in the embassy in Tehran. The hostages were freed after a failed rescue attempt in the Carter Administration, only minutes after Ronald Reagan took office, January 20, 1981.

Germany built an unfinished commercial power reactor at Bushehr, a typical LWR, specifically a PWR. However, it was eventually revealed that Iran, although a member of the NPT, had not provided the information to the IAEA, as required by the NPT, in regard to Iran’s clandestine enrichment capability. Iran claimed at the time that the United States was acting in violation of the NPT by preventing Iran, as a non-nuclear-weapon state (NNWS) from exercising its inherent right under the NPT to the beneficial use of nuclear energy for non-military purposes. The United States and others claimed that Iran was violating the NPT—not because what it was doing was inherently illegal, but because it hadn't given the required information in a timely fashion—about 18 years or more.

Once the enrichment program was revealed, the IAEA was able to inspect it at Natanz, and soon it became known that there was an even more secret enrichment program at Fordo, more deeply buried and largely immune to attack by conventional bombing. Even more troubling were reports of a computer hard drive provided to the West. The content of this hard drive has not officially been made public, although it might have been unofficially been released on Wikileaks. It is characterized by Iran as a fabrication.

In any case, as might be imagined, the intelligence services of the United States and other countries have been interested in Iran's possible program to acquire nuclear weapons, and there is a National Intelligence Estimate of December 2007 stating

- *We assess with high confidence that until fall 2003, Iranian military entities were working under government direction to develop nuclear weapons. …*

- *We assess with moderate confidence Tehran had not restarted its nuclear weapons program as of mid-2007, but we do not know whether it currently intends to develop nuclear weapons.*

Supposedly the site at Parchin was involved in this activity, and Iran has taken many measures, documented by available commercial satellite photography, with reports by various NGOs including the Institute for Science and International Security—ISIS[2] (not to be confused with the more recent "Islamic State") to remove or obscure traces of its activities there.

Paths to a nuclear weapon.

As described in my February lecture, nuclear weapons are dependent upon the fission chain reaction to go from a few neutrons to the fission of a kilogram of U-235 or Pu-239, providing an energy release of 17 kilotons—KT—of explosive energy, equivalent to the detonation of 17,000 metric tons of a high explosive such as TNT.

Given the planned availability of fissile materials—those capable in metallic form of supporting a fast-neutron chain reaction—the development of techniques for

[2] http://www.isis-online.org/

providing a practical nuclear explosive was the subject of work at Los Alamos, NM, beginning in March 1943. The straightforward approach of assembling a supercritical mass (of U-235 from two subcritical masses) was accomplished by the use of a modified naval gun, in order that the time interval between marginal criticality and full assembly be short enough to avoid pre-initiation by background neutrons from cosmic rays or from impurities in the materials of the gun.

Great conservatism in the design and the rapid pace of development and deployment led to a weaponized gun weighing some 9700 lbs. (4400 kg). This was the "Little Boy" that destroyed Hiroshima, with a yield of about 11 kt.

Although it was planned to assemble Pu-239 in the same way, an advantage being the expected greater availability of Pu than of highly enriched uranium—HEU—the so-called Thin Man program was cancelled as soon as tests at Los Alamos on reactor-produced Pu showed that the spontaneous fission of the Pu-240 impurity produced neutrons at an unacceptably high rate, so that Thin Man would almost certainly "fizzle," and provide negligible yield.

In short order, Los Alamos turned to the implosion concept, in which a shell or sphere of plutonium is assembled or compressed by the very high pressure of conventional explosive, cast into precision shapes. The high pressure and the much larger ratio of explosive mass to “active material” provide an assembly time in the tens of microseconds, rather than milliseconds for gun assembly, thus reducing the probability of fizzle to an acceptable range (about 10% for the Nagasaki bomb) and the minimum yield from the worst possible fizzle to about 1 KT. Three days after Hiroshima, the Pu implosion weapon-- Fat Man-- destroyed Nagasaki with an explosive yield of 20 KT of TNT equivalent.

Iran toyed with a nuclear weapon program up to 2003, but claims that its efforts are entirely peaceful since then, and Supreme Leader Ayatollah Ali Khamenei issued a *fatwah*—a religious ban on Iranian nuclear weapons-- and said that nuclear weapons would be unacceptable to Iran under its Shi’a Muslim religion.

Nevertheless, a crushing regime of financial and commercial sanctions was imposed on Iran by the United Nations and individual states, encouraging Iran to negotiate modifications in its civilian program that would increase the time that would be required to produce a weapon’s worth of HEU or Pu-239.

Goals of the Negotiation.

A decade ago, the United States and its allies wanted to negotiate with Iran, but the Western goal was that Iran should have no enrichment capacity at all—that "not a centrifuge would turn" as a result of the negotiation. Iran's goal in the negotiation was to eliminate the sanctions that were clearly going to affect the economy. But on both sides "sacred values" really were not subject to negotiation. Iran's constraint, in addition to the practical goal of elimination of sanctions, was to retain what it regarded as its rights under the NPT as a normal member, and the right to essentially unrestricted enrichment and even accumulation of fuel for research reactors and power reactors.

Iran also had a heavy-water research reactor in Tehran and was building a more modern one in Arak. The West saw Arak as a means for producing plutonium, and feared that a nominal 40 MWt (megawatt-thermal) reactor might be enhanced to operate at greater power (as was the case with the Israeli reactor at Dimona), and frowned on Iran having any such research reactor at all.

The negotiations of the past year or more have taken place between Iran on the one side and the "P5 + 1" on the other. That neologism stands for the P5 (permanent five members of the U.N. Security Council, which just happen to be the five states that are formally nuclear weapons states—NWS—under the NPT), and the "+1" is

Germany—a powerful industrial state, the economic leader of the European Union, with great experience in nuclear power and no activity toward nuclear weapons. Beyond the negotiations, there are the powers of the legislatures, primarily the United States Congress and the Iranian legislature. President Obama will need to make a case to the Congress, which has substantial power in regard to an Executive Agreement (both houses of the Congress—not just the Senate which would have to approve a Treaty by a 2/3 vote) and the Iranian legislature and a vigorous conservative faction in Iran, will have to be convinced that the deal is fair and does not discriminate against Iran.

The U.S. and several of its colleagues on the P5 + 1 feel that it is essential to have a *metric*, and the one most commonly adopted is the time to produce a Significant Quantity—SQ—of fissile material—25 kg of HEU or 8 kg of Pu. The question for Arak seems to be fairly well settled, with various proposals from the P5 + 1 and from various NGOs to modify the core or even the moderator of the Arak reactor so that it will be far less efficient in producing Pu. Thus, instead of using natural uranium of 0.72% U-235, with a lot of capture of neutrons in the U-238 to form high-quality Pu-239, the approach would be to use LEU fuel in a heavy water or a light-water research reactor, the purpose of which is to produce medical isotopes. Another option is to use as the “target” in the Arak reactor enriched uranium rather than natural uranium, which would enable running the reactor at lower overall thermal power.

Iran seems to have ideas of its own for the satisfactory redesign of Arak, and the outlines of an agreement are clear from the Framework that there will be no capability of reprocessing, that the irradiated fuel would be shipped out of the country, and that the design of the reactor will be modified so as to achieve the goals of much reduced Pu production[3]. In the referenced paper, David Albright and his colleagues express satisfaction with the proposed path forward on Arak, *“The Arak reactor provisions are adequate and serve as a model for this agreement and future arms control efforts.”*

As for enrichment by the centrifuge route, there are many parameters to be considered. According to Albright, *et al*, Iran has not only many IR-1 centrifuges in operation, but has built IR-2 machines and even IR-5 machines with much greater output of separative work. The nominal capacity of an IR-1 machine is about 1 kg-SWU per year—worth about $100 on the commercial enrichment market. They write, referring to the Fact Sheet released by the White House[4] on April 2, 2015,

[3] http://www.isisnucleariran.org/assets/pdf/Assessment_of_Iran_Nuclear_Framework_April_11_2015-final.pdf , *“P5+1/Iran Framework: Needs Strengthening,”* By David Albright, Andrea Stricker, Serena Kelleher-Vergantini, and Houston Wood, Institute for Science and International Security, April 11, 2015
[4] https://www.whitehouse.gov/the-press-office/2015/04/02/parameters-joint-comprehensive-plan-action-regarding-islamic-republic-ir

Other important provisions contained in the Fact Sheet include:

- *No new enrichment facilities for 15 years;*
- *The removal and monitored storage of excess centrifuges and associated equipment and not their disablement in place, as was discussed in the past as a preferred possibility by the U.S. negotiators;*
- *The removal from Iran or blending down of most of Iran's stock of ten tonnes of about 3.5 percent LEU; a clear recognition that LEU whether in hexafluoride or oxide form results in similar breakout estimates. The key variable in breakout estimates is the amount of 3.5 percent LEU, not its chemical form.*
- *Excess centrifuges and associated equipment can be used only as replacements for operating centrifuges and equipment, removing any need for further operation of IR-1 and IR-2m centrifuge manufacturing operations and procurements;*
- *Containment and surveillance of centrifuge component manufacturing plants; and*
- *A procurement channel for goods needed in authorized nuclear programs.*

There are also other provisions, both included and not included, in the Fact Sheet that contribute to an adequate deal. However, there are several key enrichment provisions that need strengthening or clarification. Breakout Timelines With *about 6,000 IR-1 centrifuges and a stock of 300 kilograms of 3.5 percent LEU hexafluoride and no available near-20 percent LEU hexafluoride, our breakout estimate would have a mean of about 15 months, where the minimum breakout time would be 12 months. We have used the mean as the best indicator of breakout time and interpret the minimum time as a worst case. Thus, our estimate of breakout would confirm the United States' assessment that these limitations satisfy a 12 month breakout criterion.*

I will not do all the calculations for you, but will show you my handy dandy SWU calculator that I placed on the FAS website in this form in 2007 and will show here how with the assumption of an "ideal cascade," the "time to SQ" can vary enormously. This, of course, motivates all of the measures that have been under negotiation for reducing the on-site stock of even LEU (3.5% U-235) and other measures to credibly extend the "breakout time" to one year.

An informed view of the status of the negotiations and the benefits and risks of an agreement is available in *The New Deal*, by Jessica T. Mathews, in the New York Review of Books[5].

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[5] https://www.whitehouse.gov/the-press-office/2015/04/02/parameters-joint-comprehensive-plan-action-regarding-islamic-republic-ir

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	**SWU per kg for various enrichment parameters.**						SWU_Calculations (version 3).xls				R.L. Garwin, 12/19/2007			
2	Row													
3	3	Xp	Xw	Xf	P	W/P	F/P	Vp	Vw	Vf	ΔSWU/	ΔSWU/	ΔSWU/	
4	4	(product)	(waste)	(feed)	kg	kg W/kg P	kg F/kg P	---------------value function-			kg produc	kg U-235	P kg of	
5	5	% U-235	% U-235	% U-235	kg of product			------------ (2x-1) ln [x/(1-x)] --				in product	product.	
10	10	19.900	0.250	0.711	1.00	41.62	42.62	0.84	5.96	4.87	41.35	207.77	207.77	
11	11	90.000	0.400	0.711	1.00	287.10	288.10	1.76	5.47	4.87	170.42	189.36	189.36	
12	12	3.500	0.400	0.711	1.00	8.97	9.97	3.08	5.47	4.87	3.64	103.89	103.89	
13	13	90.000	0.400	3.500	1.00	27.90	28.90	1.76	5.47	3.08	65.33	72.58	72.58	
14	14	3.500	0.360	0.710	1.00	7.97	8.97	3.08	5.58	4.87	3.89	111.22	111.22	
15	15	4.400	0.250	0.711	1.00	8.00	9.00	2.81	5.96	4.87	6.66	151.41	151.41	
16	16	3.500	0.400	0.710	1.00	9.00	10.00	3.08	5.47	4.87	3.64	104.02	104.02	
17	17	95.000	0.500	0.711	1.00	446.87	447.87	2.65	5.24	4.87	163.79	172.41	172.41	
18	18	95.000	0.500	19.900	1.00	3.87	4.87	2.65	5.24	0.84	18.85	19.84	19.84	
19	19	19.900	0.711	4.400	1.00	4.20	5.20	0.84	4.87	2.81	6.69	33.62	33.62	
20	20	90.000	0.400	3.500	1.00	27.90	28.90	1.76	5.47	3.08	65.33	72.58	72.58	
21														
22	**Enter your desired set** of enrichment parameters in Columns B-D for Xp, Xw, and Xf-- the U-235 conentrations in %, and in Col. E the kg of product.													
23	Rows 23-30 are formatted for this purpose, as are Rows 7-20.							If you corrupt the worksheet, download it afresh.						
24	24	4.400	0.250	0.711	1000.00	8.00	9.00	2.81	5.96	4.87	6.66	151.41	151,413.67	
25	25	4.400	0.250	0.711	1.00	8.00	9.00	2.81	5.96	4.87	6.66	151.41	151.41	
26	26	20.000	0.250	4.400	1.00	3.76	4.76	0.83	5.96	2.81	9.87	49.35	49.35	
27	27	95.000	0.250	4.400	1.00	21.83	22.83	2.65	5.96	2.81	68.64	72.25	72.25	
28	28	95.000	0.250	20.000	1.00	3.80	4.80	2.65	5.96	0.83	21.29	22.41	22.41	
29	29	95.000	4.400	20.000	1.00	4.81	5.81	2.65	2.81	0.83	11.32	11.91	11.91	
30	30	95.000	10.000	20.000	1.00	7.50	8.50	2.65	1.76	0.83	8.76	9.22	9.22	
31														

32 **SWU_Calculations (version 3).xls**. This live spreadsheet, when downloaded to any computer with Excel or a compatible program, allows the user to
33 specify the U-235 concentration (in per cent) for the "product", "waste" or "tails", and the "feed" to an ideal enrichment cascade.
34 Optionally, the mass of product (kg) in column E can be specified as well. User inputs in Columns B-E result in calculated outputs in Columns F-M
35 as indicated in Rows 3-4.
36 Thus, Column F is the kg of waste per kg of product; Col. G is the kg of feed material per kg of product. Cols. H-J provide the
37 value function (2x-1) ln [x/(1-x)] for the product, waste, and feed concentrations, respectively as briefly illustrated in the FAS SWU Calculator
38 (at **www.fas.org/cgi-bin/sep.pl**). The output Columns K-L show the Separative Work Units that must be provided by the ideal cascade to produce
39 1 kg of product, or alternatively, per kg of U-235 contained in the product. The rate of SWU production (SWU/yr) of an ideal cascade of identical
40 machines is the product of the unit SWU rating of a centrifuge and the number of centrifuges. Thus if a single centrifuge can be operated at
41 2 SWU/yr, an assembly of 3000 centrifuges could produce 2x3000 = 6000 SWU/yr, and if assembled into a suitable set of series and parallel
42 configurations would produce enriched uranium at a rate illustrated in one of the rows of the spreadsheet. Row 12 shows that 3.64 SWU must be
43 invested per kg of 3.5% U-235, for a cascade fed natural uranium with Xf = 0.711% U-235, and with a waste stream containing Xw = 0.40% U-235.
44 Thus a cascade rated at 6000 SWU/yr could produce 6000/3.64 = 1648 kg of 3.5% product per year, containing 6000/103.89 = 57.75 kg of U-235.