Gregory S. Jones[1]
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Iran's Bushehr Nuclear Power Reactor: A Potential Source of Plutonium for Nuclear Weapons

The nuclear deal signed with Iran in July 2015 (the Joint Comprehensive Plan of Action-JCPOA) paid little attention to Iran's Bushehr nuclear power reactor despite this reactor producing about 240 kilograms of plutonium each year (enough for about 48 nuclear weapons). Apparently the lack of focus on Bushehr was due to two incorrect beliefs. First, it was thought that all of the plutonium produced in this reactor is reactor-grade and second that reactor-grade plutonium cannot be used to produce nuclear weapons.[2] I plan to address the issue of the weapons usability of reactor-grade plutonium in detail in future writings. In this paper I will show that not all of the plutonium produced at Bushehr in normal operation is reactor-grade. Further, there is no requirement that the reactor be operated normally.

If a nuclear reactor is filled with the same fuel throughout its entire core, then the neutron flux and thereby the power level across the core would have the shape of a sine curve with the peak flux occurring in the center of the core. In most power or plutonium production reactors, there is usually an effort made to "flatten" the reactor's neutron flux by reducing the reactivity of the fuel in center of the core. The flattened flux allows the reactor to operate at a higher power level.

In a light water power reactor (LWR) such as Bushehr, this flattening is achieved by partially refueling the core combined with repositioning (shuffling) the remaining fuel. The Bushehr reactor is intended to be refueled once a year. Only one-third of the fuel is removed. If the reactor has been operating for at least three years its fueling cycle should have reached equilibrium. In an equilibrium core all of the fuel has an initial enrichment of 3.6%. The one-third of the fuel that is removed during a refueling is all from the central part of the core and has been in the reactor for three years. Fresh fuel with an enrichment of 3.6% is added to the outer part of the core. The fuel that was in the outer part of the core and has been in the reactor for one year is moved closer to the center of the core. Fuel that was in the middle part of the core and has been in the reactor for two years is move to the central part of the core. When the reactor restarts operation after refueling, fuel that has been in the reactor for two years is in the center of the core, fuel that has been in the reactor for only one year is in the middle part of the core and the fresh fuel is in the outer part of the core. Thus the neutron flux is flattened and a higher reactor power level is achieved.

But what happens when a reactor starts operation for the first time, since all of the fuel is fresh? In this case fuel with three different enrichments is used in the first core to achieve flux

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[1] This paper is the product of the author's personal research and the analysis and views contained in it are solely his responsibility. 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 therefore RAND should not be mentioned in relation to this paper. I can be reached at GregJones@proliferationmatters.com

[2] The U.S. defines weapons-grade plutonium as containing less than 7% Pu-240. Fuel-grade contains 7% to less than 19% Pu-240 and reactor-grade 19% or more Pu-240. *Plutonium: The First 50 Years*, DOE/DP-0137, U.S. Department of Energy, February 1996, p.17.

flattening. The Iranians have published information on the first core used at Bushehr.[3] The initial core contained 54 fuel assemblies with an enrichment of 1.6%, 67 assemblies with an enrichment of 2.4% and 42 assemblies with an enrichment of 3.6%.

The 1.6% enriched fuel is burned for only one year and then is permanently discharged. The Iranians have published the quantities of the different isotopes of plutonium contained in this fuel at the end of the one year fuel cycle. This fuel contains a total of about 92 kilograms of plutonium (enough for about 18 nuclear weapons) with the isotopic composition shown in Table 1. This plutonium is clearly fuel-grade, not reactor-grade.

Table 1
Isotopic Composition of First Discharge Plutonium from Bushehr
1.6% Enriched Fuel

Pu 238	Pu 239	Pu 240	Pu 241	Pu 242
0.1%*	76.2%	17.7%	5.5%	0.5%

*My estimate

Plutonium with a 17.7% Pu 240 content would have a significant predetonation probability if it were used in an unboosted implosion type nuclear weapon. A former nuclear weapon designer, Harmon Hubbard, has developed a methodology that allows one to calculate the probability that various yields would be produced assuming different levels of Pu 240 content and implosion technology for a weapon that has a design yield of 20 kilotons.[4]

Any country that developed nuclear weapons today, including Iran, would have weapons with a significantly higher performance than that of the Nagasaki weapon.[5] Assuming that Iran uses 1950s U.S. implosion technology,[6] I have calculated that despite a significant predetonation probability, this plutonium would produce an average yield of about 9 kilotons which would have a lethal area about 60% of that of the full yield weapon.[7] Clearly this plutonium can be used to produce powerful nuclear weapons.

The heat output of the reactor-grade plutonium produced by modern LWRs is another reason often cited as to why this plutonium cannot be used effectively in unboosted implosion nuclear weapons. Weapons-grade plutonium has a heat output of 2.3 watts per kilogram whereas the plutonium produced by fuel with an initial enrichment of 4% to 5% and burnup of 50,000

[3] Yashar Rahmani, Ali Pazirandeh, Mohammad B. Ghofrani, and Mostafa Sadighi, "Calculation of the fuel composition and the thermo-neutronic parameters of the Bushehr's VVER-1000 reactor during the initial startup and the first cycle using the WIMSD5-B, CITATION-LDI2, and WERL codes," *Annals of Nuclear Energy*, Vol. 57, 2013, pp.68-83.

[4] Harmon W. Hubbard, "Plutonium from Light Water Reactors as Nuclear Weapon Material," pp. 61-62, Appendix 3 in: Victor Gilinsky, Marvin Miller, Harmon Hubbard, "A Fresh Examination of the Proliferation Dangers of Light Water Reactors," Nonproliferation Policy Education Center, October 22, 2004 http://npolicy.org/article.php?aid=172

[5] Even fifty years ago, France's and China's first nuclear tests involved weapons significantly more advanced than the Nagasaki weapon. These nuclear devices used implosion technology similar to what the U.S. used in the 1950s.

[6] Hubbard's three times Trinity case.

[7] Even if Nagasaki technology were used the average yield would still be about 2.5 kilotons.

MWD/Te (megawatt-days per metric ton) would have a heat output of 16 to 18 watts per kilogram. Gunther Kessler has written extensively promoting the false notion of "denatured" plutonium i.e. plutonium that cannot be used to produce nuclear weapons. Kessler has claimed that plutonium with a heat output of greater than about 13 watts per kilogram would so seriously affect the high explosives used in implosion weapons that they would be unusable.[8]

In fact, Kessler only analyzed Nagasaki-level technology implosion weapons with very large plutonium cores. For implosion nuclear weapons with smaller plutonium cores using 1950s U.S. level technology, even plutonium with a heat output greater than 18 watts per kilogram can be used. However, for the first discharge plutonium from Bushehr this issue is hardly relevant. This plutonium's heat output is only 3.4 watts per kilogram, which is far below Kessler's 13 watts per kilogram limit and is much closer to weapons-grade plutonium.

Though the JCPOA requires Iran to export the spent fuel from the Arak reactor, it does not require Iran to export any of the spent fuel from the Bushehr power reactor. In the agreement Iran has simply stated that it "intends" to export the fuel. As far as is known this first discharge spent fuel is still in Iran. The JCPOA prohibits Iran from reprocessing the spent fuel from Bushehr for 15 years but the presence of this spent fuel gives Iran the option to quickly acquire plutonium for nuclear weapons should it violate the JCPOA.

Even if this first discharge spent fuel were to be exported, Iran would still have the option to obtain fuel-grade plutonium with an even lower Pu 240 content every time Bushehr is refueled. The outmost fuel assemblies in the reactor are subjected to the lowest neutron flux and at the time of refueling have only been in the reactor for one year. There are 42 such fuel assemblies which would contain a total of 68 kilograms of plutonium (enough for about 14 nuclear weapons). The Iranians have published the isotopic content of this plutonium, which is shown in table 2.[9]

Table 2
Isotopic Composition of Plutonium Contained in the Outermost Fuel at Bushehr
3.6% Enriched Fuel, One Year of Irradiation

Pu 238	Pu 239	Pu 240	Pu 241	Pu 242
0.2%*	84.2%	11.7%	3.7%	0.2%

*My estimate

With a Pu 240 content of only 11.7%, this plutonium is almost weapons-grade. Using Hubbard's methodology I calculate that if this plutonium were used in an implosion weapon using 1950s

[8] G. Kessler, *Proliferation-Proof Uranium/Plutonium Fuel Cycles: Safeguards and Non-Proliferation*, KIT Scientific Publishing, 2011, chapter 10.
[9] Yashar Rahmani, Ali Pazirandeh, Mohammad B. Ghofrani, and Mostafa Sadighi, "Calculation of the fuel composition and the thermo-neutronic parameters of the Bushehr's VVER-1000 reactor during the initial startup and the first cycle using the WIMSD5-B, CITATION-LDI2, and WERL codes," *Annals of Nuclear Energy*, Vol. 57, 2013, pp.68-83.

U.S. technology, its average yield would be 12 kilotons, which would have a lethal area about 71% of a full yield weapon.[10] The heat output of this plutonium is only 3.7 watts per kilogram.

At the time of refueling, this fuel from the outermost part of the reactor should be shuffled inward and remain in the reactor for another two years.[11] However Iran would always have the option to discharge it immediately, citing safety concerns with either the fuel or the reactor itself. Indeed Iran already temporarily discharged all of the fuel from the Bushehr reactor in 2012.

Further there is nothing that compels Iran to wait a full year before refueling the reactor. Iran could shut down the reactor and remove this outermost fuel after only half a year. Iran would then have access to about 35 kilograms of plutonium (enough for about 7 nuclear weapons) that would have a Pu 240 content of less than 7%, which would be true weapons-grade.

I am not the first to point out the problem posed by the plutonium contained in the initial fuel discharge from a LWR. Such concerns were raised 15 years ago with regard to plans to build LWRs in North Korea.[12] Now these concerns have been verified by Iran's own published calculations. Clearly the JCPOA should have paid more attention to the proliferation risk posed by the Bushehr reactor instead of assuming that it is completely benign.

Whether LWRs are appropriate for a given country needs to be determined by balancing the proliferation risk with the need for nuclear energy. Iran with its abundant oil and gas resources has little need for nuclear energy and Iran's past violations of International Atomic Energy Agency safeguards shows that it is a significant proliferation risk. Clearly, LWRs are not appropriate for Iran yet Russia is reported to have started work on two more nuclear power reactors which will provide Iran with access to even more plutonium. Unfortunately it will be difficult for the U.S. to oppose these new reactors since the JCPOA grants Iran "its right to nuclear energy." In the future, policy makers should take a much more realistic view of the proliferation dangers posed by LWRs when evaluating the appropriateness of nuclear power in any given country.

[10] Even if used in a Nagasaki type weapon this plutonium would produce an average yield of about 5 kilotons.

[11] If this fuel with an initial 3.6% enrichment remained in the reactor for the full three years, its burnup would be about 37,000 MWD/Te. The plutonium in this fuel would have a heat output of only about 13 watts per kilogram i.e. barely Kessler's limit.

[12] *Verifying the Agreed Framework*, the Center for Global Security Research, Lawrence Livermore National Laboratory and the Center for International Security and Cooperation, Stanford University, UCRL-ID-142036 and CGRS-2001-001, April 2001, p.49.