



International Journal of Nuclear Security

Volume 4 | Number 1

10-8-2018

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Recommended Citation

Ghoshal, Debalina (2018) "Iran's Arak Heavy Water Reactors: Past, Present and Future," *International Journal of Nuclear Security*: Vol. 4: No. 1, Article 6.
Available at: <https://trace.tennessee.edu/ijns/vol4/iss1/6>

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Iran's Arak Heavy Water Reactors: Past, Present and Future

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Abstract

The Iranian nuclear impasse involved issues related to centrifuges and uranium enrichment, the Fordow underground enrichment plant and the IR-40 Heavy Water Reactors (HWRs).

It is in this context that the paper tracks the development of the Arak HWRs prior to the nuclear deal and the concerns regarding the HWRs during the nuclear negotiation process and the neutering process post Joint Comprehensive Plan of Action (JCPOA). The paper further discusses whether Iran could resort to nuclear weapons with either enriched uranium or HWRs.

I. Introduction

The Iranian nuclear impasse consisted of the issues pertaining to centrifuges and uranium enrichment, the Fordow underground enrichment plant and the IR-40 heavy water reactors (HWRs). However, it was the IR-40 HWR at the Arak facility that became a very controversial issue during the nuclear negotiation process, during and following the implementation of the Joint Plan of Action (JPA) in 2013. It was subjected to enormous global criticisms, and, according to a BBC report, was one of the toughest sticking points to deal with. HWRs require natural uranium, as opposed to enriched uranium, for fuel—which Iran has in abundance; therefore, the alternative method for Iran's nuclear program was believed by the state to be ideal. The European 3 (E3)—Britain, France, and Germany—and the United States feared that the IR-40s would be capable of producing plutonium to develop nuclear weapons. In November 2013, a historic deal was achieved under the JPA when Iran agreed to limit its nuclear program in accordance to the demands of the P5+1. In the JPA, the P5+1 (Britain, France, China, Russia, and the U.S. + Germany) demanded that Iran neuter the Arak HWRs as an obligation of the nuclear deal.

The JPA reached its final stage with the completion of the Joint Comprehensive Plan of Action (JCPOA) in July 2015. In return for curbing its nuclear program, the P5+1 would lift the sanctions that were imposed on Iran. However, these sanctions would only be lifted once the P5+1 were confident that Iran was abiding by the nuclear deal, and these assurances would be based on the International Atomic Energy Agency (IAEA) reports. The JCPOA demanded several other compromises on Iran's nuclear program that also included reducing the number of centrifuges, acceding to the Additional Protocol (AP), and adopting the Modified Code 3.1. However, the reason the HWRs remain an intriguing issue is because of the

ability of the reactor to produce plutonium that is lightweight, cheaper, and more powerful than enriched uranium warheads. Additionally, Iran's venture into multiple re-entry vehicles (MRV), which require miniaturized nuclear warheads for which plutonium warheads are ideal—as they are lightweight and easier to miniaturize than enriched uranium—has become an issue of concern.

In such a context, this paper tracks the development of the Arak HWRs prior to the nuclear deal and the concerns regarding the HWRs during the nuclear negotiation process and the neutering process post-JCPOA. The paper also discusses the nuances of President Trump walking out of the nuclear deal and whether such a step could provide scope to Iran to develop nuclear weapons.

II. History of the Arak HWRs

Iran's desire to construct the Arak IR-40 HWRs dates back to the 1980s. Since then, research and development has been carried out for the production of heavy water at the Esfahan Nuclear Technology Centre (ENTC) [1]. While the heavy water-related research conducted at Esfahan continued, it was only in 2002 that Iran decided to build the IR-40 at the Arak facility.

Iran's justification for constructing the IR-40 was that it had not received any foreign technical assistance to replace its obsolete Tehran Research Reactor (TRR), a light water reactor (LWR), and that it was lacking the required fuel for its nuclear program. Tehran received this LWR for the reactor, as well as weapons-grade uranium fuel for it, from the U.S. in 1967 under the U.S. Atoms for Peace program [2]. However, following the Iranian Revolution in 1979, Iran was no longer able to procure any fuel from the U.S. or Europe. It managed to receive fuel from Argentina, but even still, by 2010 Iran was running out of fuel for its reactor [3].

According to Iran, this shortage of fuel also coerced Iran to accelerate its development of HWR. Iran further justified the construction of HWRs on grounds that there was a sense of uncertainty regarding the future of their centrifuge program and that they feared they could have succumbed to Western pressure [4]. Iran also feared that acquiring enriched uranium from abroad would become difficult, so relying on natural uranium that would use heavy water as a moderator was regarded as a viable alternative [4].

Iran's HWR program was also assisted by both China and Russia. The Research and Development Institute of Power Engineering (NIKIET) was Russia's main research and design centre for nuclear power plants, and D.I. Mendeleev Russian Chemical-Technological University gave Iran technical assistance for the construction of HWR research and related heavy water technologies [5]. This cooperation breached the agreement between the U.S. and Russia wherein Russia was to provide assistance only for the Bushehr plant. Such a move by Russia coerced the U.S. to sanction the two above mentioned institutes in Russia [4]. Studies reveal that the fuel rod bundle for fuel fabrication in the IR-40 is similar to the fuel rod bundle used in the modified Russian Reactor Bolshoy Moshchnosti Kanalnyi (RBMK) reactor, a Soviet-era LWR.

NIKIET and a Russian company in Obninsk provided key technology for the Arak reactor which included modifying the design of the RBMK fuel rod bundle to be used with the Arak HWR [6]. This cooperation preceded the A.Q. Khan network that had made it possible for Iran to acquire centrifuge technology. Unlike the Soviet RBMK reactor, the IR-40 was an HWR and used heavy water as a coolant and moderator [7]. HWRs require plenty of water to run, and thus, in order to be able to easily access heavy water, the Arak facility is located at the Qatran workshop close to the Qara-Chai River in the Khondab region in central Iran. According to reports, China provided heavy water to Iran in the 1990s, as Iran's HWPP did not have the capacity to produce enough heavy water to support the IR-40 [8]. In 1991, China reportedly supplied a 100Wt Heavy Water Zero Power Reactor to Iran so that Iran could gather the requisite expertise for controlling the HWRs [4].

Toward the beginning of the new millennium, the National Council of Resistance of Iran (NCRI), an opposition group in Iran, disclosed Tehran's clandestine nuclear program for the first time. The NCRI is a parliament-in-exile striving to set up a secular democratic government and which opposes nuclear proliferation and production of weapons of mass destruction and ballistic missiles. The IR-40 HWR received criticisms as the reactor was to produce plutonium that could have been diverted into a "possible military dimension" (PMD).

The NCRI also accused Iran of using a frontline company called the Mesbah Energy Company to prevent unwanted disclosures regarding the work progress at the Arak facility [9]. In fact, more recently, despite Iran's assurance that it is abiding by the JCPOA and the IAEA—claiming that Iran is in compliance with the JCPOA—NCRI has accused Iran of continuing its nuclear weapons program. According to NCRI, the Organization of Defensive Innovation and Research in Iran, known as the SPND (and headed by an IRGC Brigadier General), is carrying out nuclear weapons-related activities in the same scale as the activities prior to the JCPOA of 2015.

There were two different facilities for the Iranian HWR program: the HWPP at Arak and the 40 MW (th) IR-40 reactor—the construction of which was planned to begin at Arak in 2004 [9]. Modern Industries Technique Company was responsible for the design, construction, and development of the HWR [4]. In 2002, in a letter to the IAEA, Iran expressed its desire to develop the IR-40 and provided preliminary design information, but the letter contained no information on the fuel or reactor design. The drawings had no reference to the hot cells (explicated herein), despite the fact that the facility indulged in radioisotopic production. This was of particular concern for the IAEA since, reportedly, Iran was seeking to acquire heavy manipulators from abroad to be utilized in large hot cells [10]. Iran also acknowledged its desire to use hot cells for the production of radioisotopes. By 2003, then Iranian President Seyyed Mohammad Khatami acknowledged the existence of the Arak facility and the development of the IR-40 HWRs. In 2003, Iran also delivered a presentation to the IAEA on the technical features of the IR-40 and informed the IAEA that it would commence construction in 2004. HWRs are not free of the complexities of nuclear proliferation, as they can be used to produce weapons-grade plutonium and need not undergo the complex procedure which enriches uranium. The IR-40 used natural uranium as fuel, and nuclear weapons can be produced more rapidly from natural uranium than from low-enriched uranium (LEU) [9].

Iran further acknowledged that the capsules that contained pellets were irradiated at the TRR in order to produce the fission product isotopes: molybdenum, iodine, and xenon (MIX). In fact, Iran began construction of a MIX facility in 1995 but never commissioned it, as the neutron flux of the TRR was not adequate for allowing production of radioisotopes with natural uranium targets [11]. Iran further affirmed that some of the capsules were processed [11]. Plutonium was separated from irradiated uranium dioxide targets in three shielded glove boxes. However, Iran assured that these activities of irradiation and plutonium separation had already been terminated in 1993 [12], and until 1999, Iran claimed that the glove boxes were used for iodine production—after which they were dismantled and sent to ENTC in 2000 and, since which, have been stored there. Iran stated that this was done to gain expertise in a nuclear fuel cycle.

In 2003, the IAEA managed to gather samples from the separated plutonium presented to them as plutonium solution in two bottles. The IAEA concluded that the "highly radioactive materials characteristic of irradiated targets" was present, and also concluded that the amount of plutonium separated was understated [11]. Additionally, the IAEA suspected that the age of the plutonium was less than the 12-16 years, as claimed by Iran. The IAEA confirmed the presence of Pu-240 and Pu-241 isotopes, as well as Pu-239. Uninstalled cooling pumps also became a major cause of concern for the P5+1. In fact, one of the major reasons for delay in the Arak construction was the lack of cooling pumps

and control systems [13]. Cooling pumps ensure a heat transfer from the reactor core to the steam generators which act as a forced primary coolant flow.

In 2003, the U.S. suspected a French company of illegally providing Iran with four specialty pumps capable of being used for commercial purpose and military applications. The United States Treasury and Commerce Department officials suspected that cryogenic fluid transfer pumps could be used as cooling systems in Iran's nuclear reactors [14]. By 2004, IR-40s could produce eight tons of heavy water per year [14]. Also in 2004, Iran admitted that the above-mentioned plutonium quantity produced by the IR-40 had been understated. This discrepancy in the measure of plutonium quantity occurred because in 2003, the separated plutonium was stored in solution as plutonium nitrate in two small bottles which were provided to IAEA for verification. However, the contents of one of the bottles had completely leaked, making it difficult to determine the contents' original quantity. While Iran estimated the quantity to be 200 micrograms, the IAEA estimated it to be ten times greater, 2 milligrams [11].

The Arak facility was intended to be a pilot facility for conducting tests for the Girdler Sulfide Process [11]. The Girdler Sulfide Process uses gaseous hydrogen sulphide for the extraction process to reduce the cost of heavy water separation. In this process, the water is enriched to 15% heavy water with the assistance of a chemical exchange with hydrogen sulphide (H₂S). This enrichment is followed by simple distillation to produce 99.8% heavy water. As water moves from hot to cold towers, followed by small towers while it is enriched, the purified water enters the cold tower, moves down, and meets the H₂S that was entering the bottom on tower internals. After this, there is an exchange of deuterium [15].

In 2005, Iran confirmed to the IAEA that plutonium nitrate in two bottles had been purified and converted into a number of plutonium disks for alpha spectroscopy in 1995 and 1998 [11]. In 2006, the then Iranian President Mahmoud Ahmadinejad inaugurated a new phase of the HWR project. The HWPP was also commissioned in 2006. However, considering the concerns of the West, Ahmadinejad clarified that the project posed no threat to any other state [16] and that the nuclear program, including the reactor facility, would not be diverted for nuclear weapons and was intended for peaceful purposes. Despite this assurance from the President, the West was apprehensive of Iran's IR-40 reactor. This is because, from 2006 until the JPA of 2013, Iran failed to submit the Design Information Questionnaire (DIQ), a form describing the nuclear facilities' details, to the IAEA [17].

Further lack of updated information on the IR-40s defied the prerequisite of the Additional Protocol (AP) of the IAEA. But at that time, Tehran had only signed the AP and had not yet ratified it, and therefore, the AP safeguards did not apply to the Iranian nuclear program [18]. Despite the United Nations Security Council (UNSC) Resolution 1696, Iran continued work at the Arak facility [19]. In 2007, UNSC Resolution 1737 was passed, which demanded that Iran halt heavy water-related activities within a sixty-day period [15], but Iran continued with the work at the Arak facility. In 2008, the then head of the AEOI, Gholam Reza Aghazadeh, announced that Iran had produced nuclear pellets for the first time for the IR-40 reactor. In 2009, President Ahmadinejad officially inaugurated the Fuel Manufacturing Plant (FMP), which was intended for the IR-40. The same year, the IAEA conducted a Physical Inventory Verification (PIV) and DIV at the FMP, concluding that the final quality control equipment was installed [20].

In May 2010, IAEA inspectors revealed that sensitive equipment used to extract plutonium for nuclear weapons had gone missing [21]. There were also reports that Iran was conducting pyro-processing, a treatment process for spent fuel. U.S. officials view pyro-processing as reprocessing. Iran had initially stated that it was involved in this process but later failed to provide the IAEA with any relevant information on the program. By 2010, President Mahmoud Ahmadinejad unveiled a long and thin fuel assembly resembling the RBMK for the IR-40 [22]. The fuel pins in the Arak facility were designed to have zirconium cladding for which a zirconium plant was established at the Esfahan plant [22]. Zirconium is one of the best materials for ensuring nuclear safety because of its transparency to neutrons, which

affords it a good temperature performance and the ability to withstand corrosion [23] with a greater fuel burn and a low risk of nuclear proliferation.

In 2012, four men—one German and three dual German-Iranian citizens—were arrested by German police for providing valves to Iran for HWRs in defiance of the UN embargo imposed on Iran [24]. The same year, it was also reported that Iran had bought zirconium pre-forms from abroad. The thick tube pre-forms would then be thinned on a machine, called a Cold Pilger, into tubes used for the fuel cladding. The original Cold Pilger machine in the Zirconium Power Plant (ZPP) was supplied by China [8].

According to reports, Iran failed to provide detailed design information of the hot cell equipment for producing radioisotopes and even failed to provide information on the existence of the HWPP that would provide heavy water for the IR-40 [4]. Also, in 2012, when the IAEA conducted a Design Information Verification (DIV) at the Arak facility, the IAEA reported that Iran had pursued the design of installation of cooling and moderator circuit piping [4].

In May 2013, Iran announced to the IAEA that Phase 1—pre-commissioning (using dummy fuel assemblies and light water)—would be completed in the fourth quarter of 2013, while Phase 2—commissioning (using real fuel assemblies and heavy water)—would take place in the first quarter of 2014 and was expected to become operational during the third quarter of 2014. The same year, Iran further announced its plans to produce 55 fuel assemblies [9]. However, Iran refused to allow the IAEA any access for collecting samples of its Uranium Conversion Facility (UCF) where the heavy water was stored.

Additionally, Iran also deployed anti-aircraft guns (AAGs) and surface-to-air missiles in 2013 to protect the Arak facility, which made the West suspicious that Iran's nuclear program possessed a PMD. Compared to the Fordow and Natanz facilities, the Arak facility had heavy deployment of AAGs. This is because, unlike Fordow, which was buried inside a mountain, and Natanz, which was nearly underground, Arak was constructed above ground and therefore was more susceptible to enemy attack [25]. Iran also made sure that the Arak facility was surrounded by barbed wire fencing [26].

In 2013, Ali Akbar Salehi, Iran's nuclear chief, asserted that depriving Iran of the Arak would mean depriving Iran of its right to pursue a peaceful nuclear program. However, Salehi did clarify that the plutonium produced at the Arak was not suitable for nuclear bombs. In 2013, Abbas Araqchi, Iran's deputy foreign minister, also echoed Salehi's views that the Arak would need to be kept as an HWR facility [27].

Even though Iran claimed that the IR-40 was designed for industrial-level radioisotopes and medical isotopes (especially the molybdenum-99 used for cancer treatment), the P5+1 suspected that these reactors would have the capability of producing plutonium for nuclear weapons, even though Iran did not have the capability to separate spent fuel. Regarding the Molybdenum-99 that Iran imported from Russia for medical isotopes, Iran raised the issue of large portions of the isotope decaying during travel, and considering the short life of molybdenum-99, they could not have been stockpiled; therefore, they would need to be continuously produced [28].

Iran also views the Arak reactor an example of technological prowess, as evident from Salehi's remark that the reactor is "one of the prestigious projects at a national level" in Iran and terming the construction of the reactor as a "heroic action" [29]. HWR does not need to shut down for refueling, enabling them to operate for longer periods with increased reliability [30].

The P5+1 estimated that the IR-40 reactor could produce approximately 9-10 kg of plutonium annually—enough to produce nuclear weapons—and thus believed that the Arak facility had a PMD. However, Iran

continued to work on its Arak HWRs, and by 2011, the Atomic Energy Organization of Iran (AEOI) confirmed that it had completed 75% of the development work [31]. Despite the fact that, post-2003, Iran made its IR-40 HWRs open to inspection by the IAEA, post-2006, Iran denied IAEA any detailed design on the Arak HWRs, and beginning in 2011, Iran completely denied IAEA all access to its Arak facility [31].

III. IR-40 and the Nuclear Negotiation Process

As mentioned, since plutonium bombs are lighter, they are easier to miniaturize than enriched uranium warheads and thus are more suitable to be armed with cruise missiles, ballistic missiles, and multiple independently targetable re-entry vehicles (MIRVs)/multiple re-entry vehicles (MRVs). Both Iran's ballistic missiles and the long-range Soumar cruise missiles are nuclear-capable. Tehran has also developed MRV technology and could therefore use nuclear warheads.

India, North Korea, and Pakistan have focused on developing plutonium nuclear warheads. Therefore, it was only natural that the P5+1 would raise suspicion of Iran's ability to produce plutonium. This concern was evident in a U.S. officials' 2013 statement, "We have very serious concerns about [Iran] having a plutonium capability, another pathway for fissile material for nuclear weapons" [32]. The large size of the reactor had led the West to believe that the reactor may have the ability to utilize nuclear potential for more than strictly industrial and medical purposes.

During the nuclear negotiation process, one of the nuclear experts' suggestions was to alter the fuel from natural uranium to low-enriched uranium (LEU) so as to slow down the process of producing plutonium that would prevent the development of bombs. There were also suggestions to convert the IR-40s into LWRs. LWRs also make it difficult to manufacture nuclear weapons for especially clandestine nuclear weapons programs, as they take considerable time and effort, and it would be uneconomical to divert reprocessing plants to the development of nuclear weapons. However, Iran refused this suggestion of converting the reactors to LWRs. An Iranian government spokesperson, Hamid Babei, stated, "Iran cannot convert its heavy water reactor to a light water facility" and argued that it was too late to make such alterations [33]. According to Salehi, LWRs, such as the one in Bushehr, are used to produce electricity, while HWRs would be used to produce medical isotopes for treatment, making it impossible for Iran to agree to develop LWRs at the Arak facility [33].

Iran has always justified its nuclear program on the basis that it had been a signatory to the Non-Proliferation Treaty (NPT). Under Article IV of the NPT, Iran has the right to pursue a nuclear program for peaceful purposes. Hence, the NPT does not provide any restrictions on member states that they cannot develop HWRs or that they must be restricted only to LWRs. The NPT also does not oblige member states to only use LEU; member states can use natural uranium for nuclear programs as well. The NPT also does not prohibit member states from indulging in plutonium production. However, under the JPA of 2013, Iran was ordered to halt work on the Arak HWR. In April 2014, Salehi also confirmed that the issue of the HWR was "virtually resolved," with Iran offering to redesign the heart of the Arak facility [34].

Under the JCPOA of 2015, Iran committed that it would not produce or test natural uranium pellets, fuel pins, or fuel assemblies, which are designed to support the Arak reactor. Under the IAEA safeguards agreement, existing natural uranium pellets and IR-40 fuel assemblies would fall under IAEA monitoring until the modified Arak reactor becomes operational. The natural uranium pellets and IR-40 fuel assemblies would then be either converted to uranyl nitrate hexahydrate (UNH) or replaced with the same quantity of natural uranium.

Iran was to also technically modify its natural uranium fuel production process line to supply fuel for the IR-40 reactor design so that it could be utilized in the fabrication of the fuel reloads for the modernized Arak reactor [35]. Following the JCPOA, Iran pledged to remove the core from the reactor. The P5+1 believed that this would eliminate the threat of Iran developing plutonium nuclear bombs. According to reports in January 2016, Iran filled the core with concrete. However, Iran initially refused to cut the core into parts as demanded by the P5+1 as, according to AEOI spokesperson Behrouz Kamalvandi, Tehran wanted to keep the core as a “symbol of Tehran’s nuclear industry” [36]. Kamalvandi has further confirmed that only the calandria’s cavities, and not the heart of the reactor, will be filled with concrete [37].

Calandria is a reactor core vessel made from stainless steel, containing heavy water and a moderator to moderate neutrons for achieving nuclear fission [38]. Pressure tubes containing fuel assemblies are loaded in the channels of the calandria, with heavy water (as coolant) flowing around the zircaloy tubes inside the pressure tubes. This is done to extract the heat released during fission, transferring it to the light water secondary coolant to boil for generating steam [39]. Calandria is unique to CANDU reactors, providing passive heat sink by controlling the heavy water temperature for certain accidental scenarios due to a loss of coolant, along with the failure of the Emerging Control Cooling System (ECCS). ECCS provides an alternative means of cooling the reactor fuel [40].

Heavy water is one of the most efficient moderators because of its fast-moving neutrons, which readily collide with the deuterium nuclei in the heavy water molecules [41]. The presence of both neutrons and protons in the HWR, as opposed to only protons, make the heavy water denser. Heavy water moderates the reactor less efficiently than normal, light water, implying that deuterium, the heavy isotope of hydrogen, will absorb fewer neutrons, which are released spontaneously by the system’s fuel. With more neutrons in the core of that reactor, the natural uranium fuel, which is comprised of more than 70 percent uranium, is isotope U-238. The excess neutrons will be absorbed by the natural uranium while transmuting the uranium to plutonium-239 [41]. Due to this process, natural uranium is best-suited for the production of plutonium. If more neutrons are needed, heavy water reactors are then designed to operate at high power, which requires more nuclear fuel and larger reactor cores [42].

In December 2013, post-JPA, Iran allowed the IAEA to visit the Arak facility for the first time in two years. The JPA also demanded that Iran ship out the spent fuel from the Arak reactor to a P5+1 country or other country for further treatment or disposition “as provided for in relevant contracts to be concluded, consistent with national laws, with the recipient party, within one year from the unloading from the reactor or whenever deemed to be safe for transfer by the recipient country” [39]. Iran lacked a reprocessing facility despite its attempts to develop and acquire one.

The U.S. believed that the hot cells possessed by the IR-40 reactor are sufficient for research-scale plutonium extraction once they are completed. The nuclear deal therefore, demanded that for 15 years,

“Iran will only develop, acquire, build, or operate hot cells (containing a cell or interconnected cells), shielded cells or shielded glove boxes with dimensions less than 6 cubic meters in volume compatible with the specifications set out in Annex I of the Additional Protocol. These will be co-located with the modernised Arak research reactor, the Tehran Research Reactor, and radio-medicine production complexes, and only capable of the separation and processing of industrial or medical isotopes and non-destructive (Post Irradiation Examination) PIE” [39].

Iran argued that the hot cells are actually empty concrete shells, since Iran has not been able to purchase, from abroad, robotic manipulators and radiation-shielded glass—two crucial components for hot cells. Hot cells are used to “manipulate radioactive substances.” They can be utilized for peaceful nuclear

purposes as well as for separating plutonium from spent fuel [43]. Similarly, they were also useful in medical isotope separation [44]. Robotic manipulators are used to handle radioactive materials remotely. They can be used as an efficient and safe way to transfer radioactive waste from a transfer cask to the shipping containers for shipping of the waste materials to other sites [45].

However, JCPOA, which prohibited Iran from pursuing a reprocessing facility, reduced the scope for Iran to acquire the robotic manipulators and radiation-shielded glass for the hot cells for reprocessing work [46]. Under the JCPOA, Iran was not allowed to develop, build, acquire, or even operate hot cells capable of performing PIE for any reactor other than the Arak [47]. If Iran was to acquire hot cells, they would have needed to acquire it through the monitored Procurement Channel, which further limits any scope to build a covert reactor and reprocessing facility [48]. Shipping the spent fuel negated one of the limitations of the nuclear deal—that Iran would need to commit to not reprocess spent fuel or separate plutonium for a minimum of 15 years; after 15 years, it could reprocess spent fuel [48]. However, as the spent fuel will now be shipped, it leaves less potential for reprocessing.

Under the deal, Iran agreed to enrich uranium in the form of uranium dioxide (UO₂), up to 3.67% and to maintain a full core load mass of 350 kg of UO₂ [48]. Iran also agreed that fuel design would be reviewed and approved by the Joint Commission. First, fuel core load would be fabricated by the international partnership with Iran (fabricated outside of Iran); while, for future core loads, Iran would cooperate with other countries for technical assistance—to fabricate, test, and license fuel fabrication capabilities in Iran. Destructive and non-destructive testing of this fuel, including Post Irradiation Examination (PIE), would take place in one of the participating countries outside of Iran. Iran was also to work with one of these countries along with the IAEA, in monitoring the licensing of the subsequent fuel fabricated in Iran for the use in the redesigned reactor. While modernizing the reactor, care would be taken that power must not exceed 20MWth [48].

Post-JCPOA, China was to assist the Iranians in modifying the IR-40 by “redesigning and refurbishing” the reactors in order to reduce the plutonium output [49]. According to Salehi, Iran was redesigning the reactor domestically, but was referring to China and the U.S. for reviewing the design [50]. Iran was to act as project manager, while China would be involved in redesigning and constructing the reactor. The U.S., on the other hand, was to provide technical support and review the modified reactor design. France, the United Kingdom, and Germany were also to review the design, while Russia was to provide consultative services [51]. The decision of being able to redesign the Arak reactor came as a relief for Iran, as previously the West had actually decided to dismantle the Arak reactor. If the reactor had been dismantled, Iran would not have been able to make progress on any nuclear energy program.

According to Salehi, there were three steel tanks in the Arak reactor, among which the internal tank has now been removed “because the positions of the gaps in the tank for installing fuel are different in the new [redesigned] tank” [51]. Therefore, Iran is now working on a new tank, based on the new design—one with different positions for the gaps [51]. The JCPOA demanded that Iran operate the FMP in order to produce fuel assemblies for LWRs and reloads for the modernized Arak reactor [39]. The FMP at Esfahan is the main centre for Iran’s nuclear program, as it produces natural uranium fuel rods for the IR-40 reactor [52]. The Uranium Conversion Facility (UCF) at Esfahan provides the feedstock, and the core fuel assemblies made from natural uranium dioxide would need no enrichment when uranium is turned into fuel rods.

Iran was to undergo a non-destructive PIE of fuel pins, fuel assembly prototypes, and structural materials at the Arak research reactor complex. However, there were also chances that E3/EU+3 could make their facilities available for conducting destructive testing with Iranian specialists, as agreed. This condition covered a potential limitation which could have allowed Iran to use the destructive PIE examination—e.g., dissolving the spent fuel—to expand its knowledge and experience of spent fuel reprocessing. The

deal prohibited Iran from further production or acquisition of plutonium or uranium metals or their alloys, or conducting research and development on plutonium or uranium (or their alloys) metallurgy, or casting, forming, or machining plutonium or uranium metal [52].

Iran also struck a deal with the U.S. Department of Energy (DOE) to supply the U.S. with thirty-two metric tons of heavy water, worth \$8.6 billion, from its Arak facility, since the U.S. is unable to produce heavy water [53]. While this commitment allowed Iran to shed its surplus heavy water as it is legally required to do under the JCPOA, this heavy water would have been utilized by the U.S. for nuclear magnetic resonance imaging and the protection of optical fibres and semiconductors against deterioration [53]. According to reports, Tehran was to use six tons of heavy water for domestic purposes in order to produce medical isotopes [54]. Iran was also shipping low-enriched uranium (LEU) to Russia as a part of the deal [55]. Many people in Iran were not happy with the Iranian nuclear deal, though, and a hardliner newspaper had also stated, “years of toil and blood of Iranian scientists was buried under concrete” [56].

IV. Modified Code 3.1

In 2003, after the discovery of Iran's clandestine plant in the city of Natanz, Tehran agreed—for the first time—to abide by modified Code 3.1, which required that Iran provide information on any plans to build nuclear facilities “as soon as the decision to construct or to authorize construction has been taken, whichever is earlier.” One reason why the IAEA wanted Iran to comply with the modified Code 3.1 was because it would have made it easier for the IAEA to determine if there was any PMD to Iran's nuclear program, as it would have had access during early stages of construction. Once the reactors or centrifuges reach the final stages of construction, the verification process becomes more difficult.

However, in 2007, Iran reverted to the 1976 Code, which gave the country greater leniency for needing to report new reactor plans. The 1976 Code required states to report their nuclear facilities to the IAEA in no more than 180 days [57]. In addition, Tehran's failure to provide the DIV raised criticisms of Tehran's non-compliance with the IAEA Safeguards Agreement. Since then, Iran has continued to not provide DIV. Iran maintained that since it had not signed modified Code 3.1 prior to 2003, it was not obligated to immediately inform the IAEA of its decision to construct a nuclear facility.

Tehran's Uranium Conversion Facility did not receive any nuclear material prior to 2003, and since Iran had not signed the Modified Code 3.1 in 2003, it was not obligated to provide any information to the IAEA. In 2011, an Iranian official further justified Iran's non-adherence to the Modified Code, as he believed that the Code was “merely a suggestion” and not a formal provision of the Safeguards Agreement. This debate on the Modified Code 3.1 was a sticking point in the Arak negotiation process. Iran took the issue with the IAEA's right to verify the design information provided by Iran “pursuant to the Modified Code 3.1 concerning the IR-40 reactor at Arak.” Since it reverted back to the 1976 Code, Iran felt it did not need to provide any preliminary information regarding its Arak facility [58].

However, the IAEA has stated:

In accordance with Article 39 of Iran's Safeguards Agreement, agreed Subsidiary Arrangements cannot be modified unilaterally; nor is there a mechanism in the Safeguards Agreement for the suspension of provisions agreed to in Subsidiary Arrangements.

Therefore, according to the IAEA, the 2003 agreement was still in place during the nuclear impasse and hence, the IAEA felt that Iran must comply with the Modified Code 3.1. The UNSC passed resolutions in 2008 and 2010 which demanded that Iran comply with the modified Code 3.1 and also noted that the modified Code cannot be unilaterally altered. Despite this, in Iran's safeguards report from May 2012, the

IAEA noted that “Iran remains the only State with significant nuclear activities in which the Agency is implementing a comprehensive safeguards agreement but which is not implementing the provisions of the modified Code 3.1” [57]. The JCPOA however, has made clear that Iran would need to abide by the Modified Code 3.1.

The nuclear deal opened new doors for Iran; not only has it expanded the economy, but it also boosted its nuclear energy program. In July 2016, France agreed to include Iran in the International Thermonuclear Experimental Reactor (ITER) project and to set up Iran’s first thermonuclear experimental reactor that can produce 500 megawatts of electricity [59]. The reactor would be a fusion reactor that would restrict the scope to develop nuclear weapons. Iran has also initiated nuclear cooperation with China, Russia, and Eastern European countries such as Bulgaria and Hungary.

However, there was some concern in November 2016, as Iran was reported to have surpassed the 130 metric ton threshold of heavy water that could be used in the HWRs as moderator. But Iran agreed to ship the excess heavy water out of the country [60]. In December 2016, Iran exported its excess heavy water; that is, 11 metric tons were exported, bringing its heavy water level back down below 130 metric tons. In April 2017, Iran signed a cooperation agreement with the China National Nuclear Cooperation (CNNC) for a design concept to transform the Arak reactor, as well as to provide design-related consultancy services that would suit the international safety standards.

V. Plutonium or Enriched Uranium

Could Iran develop nuclear weapons through the alternative process by using enriched uranium? The answer is probably no. This is because JCPOA not only made sure that the Arak reactors are modified, but also reduced the centrifuge numbers that can be operated by Iran to 5,060. Iran has already dismantled 4,530 centrifuges [61]. Iran was only to operate the obsolete IR-1 centrifuges, further reducing the Separated Working Units (SWU), limiting any scope to develop nuclear weapons. There would also be strict limitation on research and development of advanced centrifuges for uranium enrichment [62]. Moreover, Iran was only expected to enrich uranium up to 3.5 percent, reduced from 20 percent [33]. Iran would have also needed to move the excess 13,000 centrifuges to monitored storage and reduce enriched uranium stocks from 10,000kgs to 300kgs [63]. Therefore, with the nuclear deal, both pathways of achieving nuclear weapons were closed for Iran.

In 2015, with stringent monitoring on the Iranian nuclear program by the IAEA, then U.S. President Barack Obama assured that if Iran attempts to cheat the deal, the world will be made aware of it [1]. The redesigned Arak heavy water research reactor will not be able to produce large amounts of plutonium, its spent fuel will be shipped out of the country for the lifetime of the reactor, and Iran is not allowed to build additional heavy water reactors or a reprocessing facility to separate plutonium from spent fuel for at least 15 years. Any attempt by Iran to secretly produce or divert plutonium from the Bushehr nuclear power plant would quickly be detected. Even after 15 years, when the ban on building new heavy water reactors and a reprocessing plant would have become “voluntary” (i.e., if Iran expresses the “intent” not to build such facilities), Iran would require years to build them. Although the Arak reactor will not be dismantled, Iran would require at least a few years to convert the reactor back to its original specifications, and the effort would be easily detected [49].

VI. The Future of Arak

Amid growing concerns about Iran’s nuclear program (despite its having signed the JCPOA) and attempts to prevent it, Iran confirmed that the HWR would be redesigned and completed by 2022, and according to Kamalvandi, the HWR reached the second phase of completion [64]. Until Trump had called off the deal, the Arak plant was due for engineering, installation, and tapping. Two plants were to operate in the future,

with each plant being capable of producing 1050 megawatts [64]. Calling off the nuclear deal will only result in further proliferation concerns, and in the future, Iran may refuse to redesign and modify the Arak reactor to suit the demands of the P5+1. In May 2018, the U.S. re-imposed sanctions on Iran that could cripple the European firms that aim to carry on business with Iran. On the other hand, Iran will only stick to the deal now if the European Union is able to provide a lucrative package to Iran to stick to the nuclear deal [65].

However, fears are that a fueled Arak reactor would be difficult to bomb using airstrikes, should there be any suspicion of Iran developing bombs with the use of plutonium. Bombing the reactor leads to radioactive waste, which leads to catastrophe, thus risking civilian lives. As an Israeli chief of military intelligence, Amos Yadlin—who piloted one of the F-16A's that cratered Iraq's Osirak heavy water reactor in 1981 before it was due to become operational—puts it: “Whoever considers attacking an active reactor is willing to invite another Chernobyl, and no one wants to do that” [34].

From international security concerns, in case Iran produces plutonium should the nuclear deal fall apart completely, for its nuclear-capable ballistic missiles, a lighter and smaller plutonium will enable Iran to send the missiles for a greater distance. It must be noted that prior to the U.S. walking out of the deal, the IAEA had confirmed compliance of the nuclear deal by Iran, but the agency has been forbidden from entering military sites for inspection. The provisions under IAEA not only ban development of nuclear weapons, but also the creation of computer models simulating nuclear bombs or the design of explosive systems. This verification provision of military sites and access to them fall under Section T, which the IAEA is entitled to verify under UNSC 2231 [66]. Tehran has yet to ratify the AP, and protocol is awaiting ratification from the Iranian Parliament. However, in October 2017, Salehi confirmed that Iran's commitment to the AP would only be dependent on the success of the nuclear deal [67]. Now that the nuclear deal is in the doldrums, the chances of Iran ratifying the AP or even remaining committed to it could become bleak.

VII. Conclusion

The Iranian nuclear deal so far proved to be a win-win situation for both the P5+1 countries and for Iran. However, while Iran was able to restore its nuclear program with amendments and alterations, the West was able to limit any scope for Iran to divert its nuclear program for peaceful purposes. But with Trump calling off the nuclear deal, and if the European Union fails to please Iran, then Iran may have bombs in its basement ready, just like Israel. The nuclear deal would have prevented Iran from embarking on the uranium enrichment path or the plutonium path towards nuclear weapons, but if the deal does not work out, Iran will find it easy to walk both ways towards achieving nuclear weapons. However, whether Iran chooses to do so—or only pursues a nuclear energy program despite the deal not existing—is ultimately Iran's sovereign decision.

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