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How Close Is Iran to the Bomb? The Limits of Nuclear Breakout

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As prospects to revive the 2015 nuclear deal (known as the Joint Comprehensive Plan of Action or JCPOA) remain uncertain,[1] both the U.S. and Iran have escalated the rhetoric of threats against each other. On July 14, 2022, during his trip to Israel, President Biden issued a joint declaration with Israeli Prime Minister Yair Lapid pledging to use "all elements" of American power to prevent Iran from acquiring nuclear weapons.[2] On July 17, former Iranian Foreign Minister and current Head of Iran's Strategic Council on Foreign Affairs Kamal Kharazi told Al Jazeera, "It is no secret that we have the technical capabilities to manufacture a nuclear bomb, but we have not decided to do so. In a few days we were able to enrich uranium up to [60%] and we can easily produce 90%…enriched uranium."[3]

In the absence of a nuclear deal that imposes limits on Iran's nuclear program in exchange for sanctions relief, both the U.S. and Iran increasingly rely on deterrence. By threatening to use force, the U.S. hopes to deter Iran from taking the final steps toward acquisition of nuclear weapons, such as production of weapons-grade uranium and weaponization. For its part, Iran uses the threat of manufacturing nuclear weapons to deter the U.S. from taking action against it. But exactly how close is Iran to achieving its nuclear ambitions if it made a political decision to build nuclear weapons?

Estimates of how long it might take Iran to build a nuclear bomb vary not only because of different assessments of Tehran's political intentions, but also because different methods of producing nuclear materials imply different time frames. This Brief therefore examines the various options available to Iran to produce 90% enriched uranium—the basic raw material essential in order to manufacture nuclear weapons. The Brief evaluates three different scenarios:

1. Breakout: Iran produces weapons-grade uranium as quickly as possible at its declared enrichment facilities, while seeking to prevent timely detection by the International Atomic Energy Agency (IAEA) in order to delay an international reaction;
2. Sneak out: Iran produces weapons-grade uranium at secret enrichment facilities not monitored by the IAEA; and
3. Creep out: Iran gradually expands enrichment capabilities at its declared enrichment facilities, under IAEA monitoring.

Public discussion of Iran's nuclear threat usually focuses on the breakout option: Iran racing to build nuclear weapons as quickly as possible. (Think of the U.S. Manhattan Project during World War II.) But this Brief argues that nuclear breakout is not the most likely alternative Iran will choose should it decide to build nuclear weapons. Under the current monitoring by international inspectors and foreign intelligence agencies, breakout at Iran's declared nuclear facilities would be quickly detected, and would expose Iran to aggressive international response, including heavier international sanctions and even military attack.

To avoid those risks, Iran has sought in the past to *sneak* out by attempting to produce weapons-grade uranium at secret enrichment facilities. But this effort was foiled by leaks and espionage and once the secret nuclear activities were exposed, Iran was forced to allow international inspection at the secret enrichment plant under construction and suspend many elements of its nuclear weapons program.[4] As far as can be determined, Iran's nuclear establishment remains thoroughly penetrated by foreign intelligence agencies, which means that construction of a secret enrichment plant (which would take years to complete) is very likely to be detected before any such facility can begin operations.

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Since the U.S. withdrew from the JCPOA in 2018, Iran has not "raced ahead" with its nuclear program, as some media accounts claim. As this Brief argues, Iran has instead pursued a much more cautious strategy of creep out: gradually advancing its enrichment and other nuclear capabilities in incremental steps, at a pace shaped by diplomatic calculations. This strategy is calculated to enhance Iran's bargaining leverage and its nuclear capabilities without triggering a strong international reaction. So far, the strategy has worked, but it will be more difficult to sustain if negotiations to revive the JCPOA collapse, especially if Iran declares that it intends to begin producing small amounts of 90% enriched uranium under IAEA safeguards.

The Stuff That Bombs Are Made Of

For Iran, as for most countries, production of sufficient fissile material (Plutonium-239 or Uranium-235) is the most difficult technical challenge involved in producing nuclear weapons. In Iran's case, Uranium-235 is the only near-term option for acquiring fissile material because Iran is not currently capable of producing Plutonium-239 in sufficient quantities for nuclear weapons production.[5] Natural uranium consists of a small percentage (0.7%) of Uranium-235 mixed with a much larger percentage of the isotope U-238, which is non-fissile. Uranium enrichment is a process for separating isotopes of uranium in order to increase the concentration or percentage of U-235 to the higher levels

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required for nuclear power fuel and for nuclear weapons. For example, modern light water nuclear power reactors typically require fuel enriched up to about 4–5% U-235 (called low-enriched uranium), while uranium enriched to around 90% U-235 (called weapons-grade or highly enriched uranium) is typically used in nuclear weapons production.

Iran uses a type of enrichment technology known as gas centrifuge: a hollow tube, usually manufactured from high strength metal alloys or carbon fiber, that spins uranium in gaseous form (UF6 or uranium hexafluoride) at very high speeds in order to separate the heavier U-238 isotopes from the lighter U-235 isotopes. Because the isotope separation in each individual centrifuge is very small, centrifuges are connected together in units of hundreds or thousands ("cascades") to produce higher levels of enrichment. The stream of uranium hexafluoride gas injected into the beginning of the cascade is called "feed," and enriched gas extracted from the end of the cascade is called "product." In Iran's case, centrifuges are grouped into cascades of about 170 machines, depending on the particular model of centrifuge. How these centrifuges are connected in a cascade varies depending on the desired level of enrichment: A cascade designed to produce low-enriched uranium is physically configured differently than a cascade designed to produce highly enriched uranium, even though the individual centrifuges are the same.

Iran's development of centrifuge technology has a long history. In 1987, Iran acquired extensive centrifuge assistance from Pakistan, including blueprints, key components, and working models of an early Pakistan centrifuge.[6] After many years of secret research and development, Iran began operating its first cascade at the Natanz enrichment facility to produce low-enriched uranium in 2006. In 2009, it began to produce 20% enriched uranium for the stated purpose of producing fuel for the Tehran Research Reactor. In 2021, three years after the U.S. withdrawal from the JCPOA, Iran began to produce 60% enriched uranium. Since the technology for producing weapons-grade uranium is essentially the same as that for producing low-enriched uranium (apart mainly from the configuration of cascades), Iran has been technically capable of producing 90% enriched uranium for many years but has chosen not to do so.

What Is Breakout Time?

One way to measure enrichment capacity is "breakout time," defined as the time required to produce enough weapons-grade (90% enriched) uranium for a single nuclear device once production of weapons-grade uranium begins. The amount of nuclear material required for breakout is usually specified as 25 kilograms of 90% enriched uranium metal, equal to about 40kg of 90% enriched UF6 when the weight of fluoride is added.[7] Estimating breakout time, however, is akin to predicting how fast an athlete will run a race that he or she has never run before. Breakout time is an estimate based on certain calculations and assumptions, with regard to centrifuge performance, the efficiency of cascade configuration, the enrichment level of feed material, and so forth. As a result, estimates of breakout time vary, depending on the assumptions made.

Estimates of breakout time are mainly based on two factors.[8] The first is the overall collective "power" of the centrifuges to separate isotopes of uranium, which is roughly determined by the power of an individual centrifuge multiplied by the total number of centrifuges. In other words, the more centrifuges and the more efficient these centrifuges, the shorter the estimated breakout time. The second important factor is the enrichment level of the feed material used to produce weapons-grade uranium. Starting with feed material that is already partly enriched dramatically reduces the amount of remaining energy required to produce 90% enriched uranium.[9]

As a result, the amount of feed material required to produce 25kg of 90% enriched uranium varies according to the enrichment level of the feed material. For example, approximately 5,000kg of natural uranium in the form of UF6—or 1,000kg of low-enriched UF6—is required to produce 25kg of weapons-grade uranium. Similarly, only about 200kg of 20% enriched UF6 and about 60kg of 60% enriched UF6 are required to produce 25kg of 90% enriched uranium. A country that accumulates a stockpile of enriched uranium will have a shorter breakout time.

Prior to the 2015 JCPOA, Iran had achieved an estimated breakout time of one to two months, based on its stockpile of 5% and 20% enriched uranium and its inventory of operating centrifuges. The 2015 nuclear deal was designed to lengthen Iran's breakout time to about one year by imposing physical limits on Iran's enrichment program for ten to fifteen years. At the time of the JCPOA, Iran had accumulated a stockpile of nearly 200kg of 20% enriched uranium UF6—roughly enough for one nuclear bomb if enriched to 90%—and a stockpile of about 7,000kg UF6 of low-enriched (up to 3.67%) uranium—roughly enough for seven bombs if enriched to weapons grade.

Under the JCPOA, Iran was required to completely relinquish its stockpile of 20% enriched UF6 and reduce its 7,000kg UF6 of low-enriched uranium to 300kg UF6 for fifteen years. The deal also required Iran to limit its enrichment level to 3.67% for the same length of time. Finally, the nuclear deal required Iran to limit enrichment to its main enrichment facility at Natanz and to halt enrichment at the smaller Fordow facility for fifteen years.

In terms of centrifuges, Iran was required to reduce its inventory of the relatively inefficient first-generation IR-1 centrifuges from 110 cascades (roughly 18,000 total machines) to 30 cascades (roughly 5,000 total machines) for ten years. Iran was also required to dismantle its 6 cascades (roughly 1,000 total machines) of more advanced IR-2m centrifuges, and to limit research and development with respect to more advanced centrifuges (IR-4, IR-5, IR-6, and IR-8). In years 10–15 of the JCPOA, Iran would be permitted to gradually replace its IR-1 centrifuges with more advanced models, which by year 15 would gradually reduce its breakout time to a couple of months—roughly equal to Iran's breakout time before the JCPOA was implemented in September 2015. In the three years from the implementation of the JCPOA in September 2015 to the U.S. withdrawal from the deal in May 2018, Iran carried out the nuclear reductions and additional monitoring required by the deal.

Creeping Out Since 2018

Since the U.S. withdrew from the JCPOA in 2018, however, Iran has gradually exceeded the limits contained in the original nuclear agreement. Iran has increased its stockpile of 5% enriched uranium, resumed its production of 20% enriched uranium, restarted enrichment at the Fordow facility, and started producing 60% enriched uranium along with uranium metal, in addition to manufacturing and installing advanced centrifuges. Tehran has also limited (but not ended) IAEA inspections and monitoring.[10] For nearly a year after the U.S. withdrew from the JCPOA, Iran continued to observe the nuclear limits of the deal, after the EU and the European parties to the agreement (the UK, France, and Germany) announced that they remained committed to implementing the JCPOA without the U.S. as long as Iran continued to comply with the nuclear limits. Only in May 2019 did Iran announce a staged plan to exceed JCPOA limits one at a time every two months, making clear that these nuclear steps would be reversed if the remaining parties to the JCPOA delivered on sanctions relief.[11] From a technical standpoint, these steps were relatively modest: for example, increasing enrichment from 3.67% to 5% and exceeding the 300kg limit on stocks of low-enriched uranium by a few hundred kilograms.

Once the Biden administration took office and talks to restore the JCPOA began in Vienna in April 2021, Iran took even more significant steps to enhance its enrichment capacity, presumably to increase pressure on the U.S. and other parties to accept Iran's conditions for reviving the 2015 deal. Iran may have also calculated that the Biden administration's desire to restore the JCPOA afforded it more latitude to advance its nuclear program with less risk of international reaction. In January 2021, for example, Iran announced that it was resuming production of 20% enriched uranium at the Fordow facility and installing cascades of advanced centrifuges (IR-2m, IR-4, IR-6) for enrichment at Natanz. Most significantly, in April 2021, Iran announced that it would begin production of 60% enriched uranium at Natanz in response to a sabotage attack on the facility widely attributed to Israel.[12] Although the European parties to the JCPOA (the UK, France, and Germany) protested and threatened to trigger "snapback" provisions in the JCPOA that would automatically reimpose international sanctions, they ultimately desisted for fear of upsetting the Vienna talks intended to restore the JCPOA.

According to the most recent IAEA report, as of May 2022, Iran has retained the 30 cascades of IR-1 centrifuges at Natanz (about 5,000 machines) permitted under the JCPOA. But Iran has also reactivated 6 cascades of IR-1 centrifuges at Fordow (about 1,000 machines) and is enriching with 6 cascades of IR-2m (about 1,000 machines), 3 cascades of IR-4 (about 500 machines), and 1 cascade of IR-6 centrifuges (164 machines), with plans to install six cascades of IR-1 centrifuges, six of IR-2m centrifuges, six of IR-4 centrifuges, and one IR-6 cascade.[13] Because the advanced models are several times more powerful than the original IR-1 machines, overall enrichment capacity will actually be greater even with a smaller number of centrifuges.

The May 2022 IAEA report estimates that Iran's current stockpile of enriched uranium in the form of UF6 is 1,056kg of UF6 enriched up to 5%, 238kg of UF6 enriched to 20%, and 43kg of UF6 enriched to 20%, and 43kg of UF6 enriched to 60%. As a reminder, roughly 1,000kg of 5% enriched uranium is required to produce 25kg of weapons-grade uranium, compared with about 200kg of 20% enriched uranium and about 60kg of 60% enriched uranium. So Iran's current stockpiles are small relative to the amount of feed material required for producing large amounts of weapons-grade uranium. If this stockpile was further enriched to weapons grade (about 90%), for example, Iran has only enough 5% enriched uranium and 20% enriched uranium feed material to produce weapons-grade uranium for about two nuclear weapons. The stock of 43kg of 60% enriched uranium is roughly two-thirds of the 60kg required to produce a bomb's worth of weapons-grade uranium.

Production rates are low. According to IAEA figures, for example, Iran is producing 20% enriched uranium at an average rate of about 10kg per month and 60% enriched uranium at an average rate of about 5kg per month. At this rate of production, it would take Iran about a year to produce enough 20% enriched uranium (200kg) and 60% enriched UF6 (about 60kg) feed material for breakout. Of course, this current rate would increase if Iran carried out its plans to install and operate additional advanced centrifuges. Moreover, Iran has begun to develop types of cascades that allow for quickly producing different levels of enrichment, and hence reduce the time inspectors would have to detect a change in enrichment levels.[14]

The Risks of Breakout

In a breakout scenario, Iran would rush to produce weapons-grade uranium as quickly as possible at its declared Natanz and Fordow nuclear enrichment facilities, which are inspected and monitored by the IAEA. Presumably, Iran would seek to delay detection by the IAEA for as long as possible in order to reduce the risk that the U.S. and/or Israel would attack the facilities before Iran could finish producing sufficient weapons-grade uranium for its military purposes. As discussed earlier, Iran has reduced the time it would take to produce enough weapons-grade uranium for a single weapon from about a year, when the JCPOA was in effect, to a few weeks, if Iran uses its stockpile of 60% enriched uranium as feed to produce weapons-grade uranium. Once this 60% stockpile is consumed, producing enough weapons-grade uranium for a second weapon would probably take a few months, using the 20% enriched uranium as feed. Of course, these timelines would shrink further as Iran gradually accumulated larger quantities of 20% and 60% enriched uranium and installed additional advanced centrifuges

The breakout option is extremely risky for Iran, however, because the IAEA is likely to detect that it has begun to produce 90% enriched uranium. Although Iran has taken various measures to limit additional IAEA monitoring required under the 2015 nuclear deal, it has not (as of yet) prevented the IAEA from carrying out its core mission of monitoring enrichment.[15] For example, in the May 2022 report, the IAEA says that it continues to have "regular access" to Iran's enrichment facilities, although it has not been permitted "daily access," as required under the nuclear deal.[16]

Once the IAEA detects that Iran has begun to produce undeclared weapons-grade uranium—or once Iran denies the IAEA access to verify enrichment levels—breakout is likely to trigger UN Security Council sanctions and demands to desist, potentially culminating in military attacks on the facilities. Presumably, in a breakout scenario, Iran would quickly remove weapons-grade uranium from the enrichment facilities where it is produced and move it to secure locations in order to avoid the risk that the material would be destroyed in an attack on the facility by the U.S. or Israel. Iran would have to assume that the transfer itself along with the sites of these locations would remain secret during the time it took to "weaponize" the raw uranium, including converting the UF6 to metal, fabricating metal nuclear weapons components, and producing and assembling the many other components of a nuclear warhead. During that period, Iran would be vulnerable to military coercion and to ultimatums to relinquish its weapons-grade uranium or suffer military attacks.

Based on publicly available information, it is extremely difficult to estimate the time required for weaponization once sufficient raw uranium is available. In October 2020, a senior officer in Israeli Military Intelligence estimated that such weaponization could take as long as two years, although production of a nuclear test device could take less than a year.[17] Presumably, Iran could shrink this timeline by fabricating and assembling the non-nuclear components of a nuclear device before beginning to produce weapons-grade uranium. The risk, however, would be that these weaponization activities might be detected by foreign governments, who would sound the alarm that Iran had decided to acquire nuclear weapons. According to one report, the U.S. and Israel have agreed informally that weaponization—along with 90% enrichment—would trigger a "Plan B" against Iran.[18]

In short, breakout carries a high risk of detection and of provoking a strong international reaction. Breakout makes the most sense if Iran calculates that it can safely disregard the threat that foreign powers (mainly the U.S. and Israel) will use military force to prevent Iran from acquiring nuclear weapons once it is revealed that Iran is producing weapons-grade uranium. Iran may make such a calculation in the future, but up to now it has been extremely cautious to avoid nuclear actions that risk triggering a military response.

Sneak Out Is Safer Than Breakout

From Iran's standpoint, sneak out—the production of weapons-grade uranium at undeclared nuclear facilities not monitored by international inspectors—is much safer than breakout. The great advantage of sneak out is that it would allow Iran to produce enough weapons-grade uranium for a small nuclear arsenal without international detection and intervention. Deployed on mobile missiles at underground facilities at several locations, even a small nuclear force would serve as a powerful deterrent against foreign enemies once Iran revealed that it had crossed the nuclear threshold.

In fact, sneak out was the strategy behind Iran's previous nuclear weapons program—the AMAD Plan or Project AMAD.[19] Around 1999, the Iranian leadership approved a large-scale plan to manufacture five nuclear weapons by 2004. One of the five commissioned nuclear weapons was to be used for an underground nuclear test, and the remaining four for the production of nuclear warheads for the Shahab-3 ballistic missile. The AMAD Plan sought to produce weapons-grade uranium at a secret enrichment facility built in tunnels under a mountain at an Islamic Revolutionary Guards Corps (IRGC) base near the city of Qom—now known as the Fordow enrichment facility. The AMAD Plan also included construction of secret facilities to convert UF6 gas into metal and to cast and machine uranium metal components for nuclear weapons—and to enable testing, research, and development with respect to the various components of Iran's nuclear weapons design.

The main obstacle to sneak out is that Iran's nuclear program has been vulnerable to espionage and exposure. In 2002, an exiled Iranian resistance group, the Mujahedin-e Khalq, published extensive details on Iran's secret nuclear experiments and on construction of the Natanz enrichment plant. Subsequently, after the U.S. invasion of Iraq in early 2003, Iran declared these secret nuclear experiments to the IAEA, allowed IAEA inspection of the Natanz facility, and ultimately suspended most activities related to the AMAD Plan. In 2006, the German intelligence service obtained extensive documents on the AMAD Plan from Iranian scientists, which led the U.S. intelligence community to conclude that Iran had conducted extensive research and development on weaponization, even as it suspended most parts of the AMAD Plan in 2003.[20]

In September 2009, the U.S., the UK, and France revealed the construction of the secret Fordow enrichment facility, which forced Iran to accept international inspection of the facility.[21] In 2018, Israeli operatives obtained a large archive of documents on the AMAD Plan from a storage facility in Iran.[22] More recently, assassinations of Iranian nuclear scientists and sabotage attacks on Iran's nuclear facilities in April and June 2021 likely indicate the presence of inside agents who cooperated to facilitate the attacks.[23] Since foreign intelligence agencies will probably continue to pursue intensive operations against Iran's nuclear program, it would be risky for Iran to assume that it can achieve sneak out in the future without detection.

Iran's Options Going Forward

Iran has the basic capability to produce weapons-grade uranium—the essential ingredient for a nuclear weapons arsenal. Since the U.S. withdrew from the JCPOA, Iran has significantly enhanced its enrichment capabilities, mainly by deploying advanced centrifuges and building up stocks of 20% and 60% enriched uranium. In a breakout scenario, Iran would produce weapons-grade uranium as quickly as possible at its safeguarded enrichment facilities. At this point, Iran's breakout time—the time required to produce enough 90% enriched weapons-grade uranium for a single nuclear weapon—has probably shrunk to a few weeks.

Nonetheless, breakout is a high-risk gamble for Iran. Although Iran has placed some restrictions on IAEA monitoring and inspections, the IAEA is likely to quickly discover that Iran has begun production of weapons-grade uranium, unless Iran completely denies the IAEA access to its facilities. Once breakout is detected, it is likely to trigger a strong international reaction, ranging from sanctions to a possible military attack against Iran by Israel and/or the U.S. And any raw weapons-grade material that Iran produces in the form of UF6 would need to be "weaponized" into a nuclear warhead—a process that could take a year or two.

Finally, even if Iran is able to produce enough weapons-grade uranium for a single bomb within a few weeks, production of additional quantities of weapons-grade uranium would take a few months, as Iran's stocks of 20% and 60% feed material are depleted. In short, breakout is highly likely to create a window of vulnerability—a period in which Iran's effort to build nuclear weapons is exposed, but Iran is not yet protected by a credible nuclear arsenal to deter foreign enemies.

Given the dangers of breakout, a far safer strategy for Iran would be sneak out: producing weapons-grade uranium at enrichment facilities not declared to the IAEA and not subject to international inspection. Iran could also build secret installations to complement the secret enrichment facility, to research and develop nuclear weapons and to fabricate a small arsenal of nuclear warheads once sufficient weapons-grade uranium was available. Successful sneak out, however, requires effective secrecy, but Iran's previous efforts to build clandestine enrichment facilities and conduct secret nuclear weapons research have been repeatedly exposed. From all evidence—documents pilfered, scientists assassinated, facilities sabotaged—it appears that Iran's nuclear program remains compromised by foreign intelligence.

Since the U.S. withdrew from the JCPOA in 2018, Iran has pursued a creep out strategy of cautious and incremental nuclear steps beyond the limits specified in the JCPOA, while continuing to comply with IAEA safeguards. This strategy has a dual purpose. First, it enhances Iran's diplomatic leverage in nuclear negotiations, as Tehran can offer to reverse the steps it has taken in exchange for sanctions relief. Second, it enhances Iran's technical capacity to produce weapons-grade uranium should Iran decide to do so in the future. At the same time, by taking limited and reversible steps, Iran hopes to avoid actions that would trigger an unwanted international reaction, in the form of additional sanctions or a military attack.

From Iran's standpoint, the creep out strategy has been effective: Iran has been able to significantly enhance its nuclear capabilities while it negotiates a return to the JCPOA. The strategy may be more difficult to sustain, however, the longer that efforts to restore the JCPOA are stalled. In that case, the U.S. and its European allies will be more likely to increase sanctions on Iran (such as by invoking the snapback sanctions provisions in the JCPOA), and Iran may take nuclear actions that inch dangerously close to redlines such as beginning to produce 90% enriched uranium in small quantities under IAEA safeguards. Iran could thereby seek to gradually accumulate a stockpile of weapons-grade uranium, as it has done with 20% and 60% enriched uranium—but the U.S. and its allies are not likely to tolerate the risk that Iran could quickly divert this nuclear material for military use.

In conclusion, Iran's pathways to produce weapons-grade uranium are risky and dangerous. Breakout is likely to provoke sanctions and/or military attack if, as President Biden recently said, the U.S. is prepared to use military force as a last resort to prevent Iran from acquiring nuclear weapons.[24] Sneak out would be a better option, but Iran has thus far failed to prevent foreign intelligence services from detecting its secret nuclear activities. Given the risks of breakout and the impracticality of sneak out, Iran is likely to continue the creep out strategy that it has successfully employed since the U.S. withdrew from the JCPOA in 2018. Over time, however, creep out may become more difficult to sustain without increasing the risk of escalation between the U.S. and Iran.

Endnotes

1 For details on the JCPOA, see Gary Samore, lead author and editor, *The Iran Nuclear Deal: A Definitive Guide* (Cambridge, MA: Belfer Center for Science and International Affairs, Harvard Kennedy School, with new foreword, 2017).

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5 Prior to the 2015 nuclear deal, Iran was constructing the Arak heavy water research reactor, which could have produced enough plutonium for one or two nuclear weapons annually. Under the 2015 nuclear deal, however, Iran agreed to "render inoperable" a key component of the Arak reactor and redesign the reactor to reduce plutonium production. According to the May 2022 IAEA report, Iran has not pursued construction of the reactor based on the original design. In addition, although Iran has conducted laboratory-scale experiments to separate plutonium from irradiated fuel, it does not possess an industrial-scale reprocessing plant.

6 For a history of Iran's centrifuge development, see Mark Fitzpatrick, ed., Iran's Nuclear, Chemical and Biological Capabilities: A Net Assessment (London: International Institute for Strategic Studies Strategic Dossier, 2011).

7 Based on documents from the AMAD project, Iran's nuclear weapons design required about 20 kg of 90% enriched uranium, equal to slightly more than 30 kg of 90% enriched UF_6.

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9 For example, enriching natural uranium (0.7% U-235) to 4.5% U-235 requires about 75% of the total energy required to produce 90% enriched uranium. The amount of energy required to enrich from natural uranium to 20% U-235 is about 90% of the total work required to produce 90% enriched.

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19 Based on the Project AMAD documents, it appears that Iran successfully designed a workable implosion system compact and light enough to be delivered by a Shahab-3 missile, with an intended yield of 10 kilotons. Iran conducted extensive experiments to fabricate and test the various components for this design, including casting and machining metal components, testing neutron initiators, and testing the high-explosive and detonation systems. It is clear that Iran made very substantial progress toward completing the measures necessary to produce a nuclear weapon (except for the production of fissile material), though it appears that Project AMAD was suspended before Iran could conduct a full-scale "cold test": a test of the full implosion system with a dummy fissile core, which is generally considered a requisite step in preparation for a successful nuclear test. See Arnold et al., "The Iran Nuclear Archive"; Albright with Burkhard, "Highlights of Iran's Perilous Pursuit of Nuclear Weapons."
20 National Intelligence Council, "Iran: Nuclear Intentions and Capabilities" (November 2007).
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