PISM REPORT

MILITARY NUCLEAR PROGRAMME OF IRAN: ITS HISTORY, SUSPENSION, AND PROSPECTS FOR THE FUTURE

JANUARY 2025

MARCIN ANDRZEJ PIOTROWSKI

THE POLISH INSTITUTE OF INTERNATIONAL AFFAIRS

MILITARY NUCLEAR PROGRAMME OF IRAN: ITS HISTORY, SUSPENSION, AND PROSPECTS FOR THE FUTURE

MARCIN ANDRZEJ PIOTROWSKI

WARSAW, JANUARY 2025

Proofreading: Brien Barnett

Technical editor and cover design: Dorota Dołęgowska

Photo cover: Filip Bryjka

E-ISBN 978-83-67487-91-7

Polski Instytut Spraw Międzynarodowych
ul. Warecka 1a, 00-950 Warszawa
tel. (+48) 22 556 80 00
pism@pism.pl, www.pism.pl

CONTENTS

LIST OF MOST FREQUENTLY USED ACRONYMS

AEOI	Atomic Energy Organisation of Iran
DPRK	Democratic People's Republic of Korea
EPAA	European Phased Adaptive Approach
EU	European Union
GMD	Ground-based Midcourse Defense
HEU	highly enriched uranium
HWR	heavy water reactor
IAEA	International Atomic Energy Agency
ICBM	inter-continental ballistic missile
IRBM	intermediate-range ballistic missile
IRGC	Islamic Revolutionary Guard Corps
JCPOA	Joint Comprehensive Plan of Action (colloq. "Iran deal")
kt	kiloton
LEU	low enriched uranium
LWR	light water reactor
MRBM	medium range ballistic missile
MW	megawatt
NIE	National Intelligence Estimate
NPT	Non-proliferation Treaty
P5+1	Five Powers + Germany
SLV	space launch vehicle
SRBM	short-range ballistic missile
UN	United Nations

EXECUTIVE SUMMARY

- Iran for a decade now has had the status of a so-called *threshold nuclear state*, one which, with its facilities and capabilities, could build a nuclear arsenal relatively quickly. According to available information, Iran is not currently working on the assembly or production of nuclear warheads, being content with its current status that allows for a policy of ambiguity. Maintaining this position gives Iran flexibility in strategic options and in negotiations, while also retaining the capability to build a nuclear arsenal in case of a change in threat assessment or a situation of necessity.

- Two decades ago, Iran halted its covert Amad Plan, which assumed the buildup of a small arsenal of five nuclear warheads. Nevertheless, with its know-how, experience, industrial infrastructure, and fissile materials on hand, Iran could hypothetically build an arsenal of 15-16 uranium-core warheads within five months. After the construction of the first nuclear device and within a decade of the first nuclear test, Iran could probably also build its first thermonuclear device and develop a more advanced arsenal.

- Iran considerably increased its uranium enrichment capability following the 2018 denunciation of the 2015 nuclear deal (JCPOA) by the first Trump administration. By taking advantage of the no-longer applicable limits of this agreement and amassing a larger stock of highly enriched uranium, Iran is trying to force the U.S. and the EU to lift their economic sanctions. There is growing concern in the IAEA and the international community about access to and monitoring of violations or breaches of the NPT at Iran's known civilian nuclear centres.

- In parallel and gradually regarding its nuclear efforts, Iran is also improving its missile arsenal to ranges up to 2,000 km. Israel remains Iran's top priority target, but within 5-10 years it also may build an arsenal of ballistic missiles that could threaten Europe or even the continental U.S. Iran's existing nuclear infrastructure and missiles (*virtual nuclear arsenal*) are already deterring the U.S. and Israel from undertaking preventive military strikes on its nuclear sites—although sabotage to delay work on a real arsenal might be resumed.

- So far, Iran's observed nuclear approach was likely to continue, even in the long term, if not for the growing Israeli-Iranian confrontation in 2024, the collapse of the allied regime in Syria, and speculation at that time about a second Trump administration returning in 2025 to a policy of containment (*maximum pressure*). The rise of the Israeli threat and the possibility of renewed tensions with the U.S. may therefore push Iran towards a final decision to build its own nuclear arsenal. Additionally, Iran may justify its arsenal by the cases of the denuclearisation of Ukraine, Iraq, and Libya, which have failed to protect the former from Russian aggression or the latter from regime change by the U.S.

- Moreover, even in the case of some nuclear compromise between the U.S. and Iran, there is uncertainty about the stability of Iranian state institutions and the succession of power after Ali Khamenei, the current politico-religious leader of Iran. The helicopter crash in May 2024 in which President Ebrahim Raisi died (considered up to then to be one of the leading successors to the post of Supreme Leader) increased the unpredictability of the regime in Iran and its future nuclear strategy after Khamenei. Even a smooth succession may result in a stronger, more determined role for the Revolutionary Guards in Iran's domestic, regional, and nuclear policies.

– The experience with previous U.S. negotiations with Iran shows that any deal limiting its nuclear capabilities requires far-reaching concessions, and often at the cost of further weakening U.S. influence in the region. However, the alternatives to such negotiations with Iran proved to be ineffective and the option of preventive strikes have been too risky for all U.S. administrations so far. Speculation about President Trump suggests a quick resumption of the "maximum pressure" policy on Iran, but Trump himself expressed willingness to reach a JCPOA-II deal, which the Biden-Harris administration failed to reach.

– Any predictions of the new U.S. administration's policies are made difficult by Trump's personality and contradictory statements about Iran during his 2024 election campaign. It is possible that his approach will reflect his personal dislike of Iran, his lack of understanding of U.S. limitations or the merits of the JCPOA, as well as his close relationship with the current prime minister of Israel and transactional attitude to other regional allies. It is also difficult to determine the real impact within the new administration of Vice President J.D. Vance, who has been a critic of the U.S. military presence in the Middle East and seems to have a greater personal distance to Israel.

– Europe has been seriously constrained in its independent initiatives towards Iran, especially in the context of a U.S. strategy totally subordinated to nuclear issues. Were it not for concerns about the sum of transatlantic relations under Trump, Europe and Poland could adopt a policy based on the assumption that there will be no permanent solution to Iran's nuclear issue, continuation of its "threshold nuclear state" status, and fluctuations in U.S. policy between the still available strategic options.

– The period of the Polish presidency of the EU in the first half of 2025 is likely to coincide with attempts for renewed "maximum pressure" on Iran from the U.S. or even some readiness of Trump for a new nuclear deal with Iran. During this time, Poland will likely have to react flexibly to further steps by the U.S., Iran, and Israel and try to ease tensions if coordination between Trump's and European positions will be lacking.

– Iran's nuclear arsenal is clearly not in the interest of Poland. However, the urgent priority for Europe and Poland should be to put pressure on Iran to limit the negative consequences of its alliance with Russia (e.g., increasing supplies of Iranian drones, ballistic missiles, and artillery ammunition) in the war with Ukraine. At the same time, Poland may prepare for various scenarios of instability of the regime in Tehran, including even its collapse, which would create more opportunities for economic cooperation with Iran.

TIMELINE OF IRAN'S NUCLEAR PROGRAMME (1957- 2025)

1957 The U.S. invites Iran to participate in the civilian cooperation programme *Atoms for Peace*.

1967 Launch of the first LWR-class research reactor in Tehran.

1968 & 1970 Iran signs and ratifies the NPT, submits to monitoring and control by the IAEA.

1974 Shah Reza Pahlavi establishes the civilian AEOI and announces the plan to build 22 or 23 HWR-class reactors in Iran.

1979-1980 Revolution and fall of the Pahlavis monarchy and the establishment of the Islamic Republic of Iran. Emigration and arrests of scientists and the interruption of the works on the Bushehr Nuclear Power Plant.

1980-1988 Iraq-Iran war: mutual and unsuccessful airstrikes on reactor construction sites in Bushehr and Tuwaitha (Osirak), repeated and massive use of chemical weapons by both sides, and a "war of cities" with the use of Scud-type ballistic missiles.

1987-1992 First phase of negotiations between Iran and the network of Pakistani scientists represented by Dr. Abdul Qadeer Khan on the topic of gaseous centrifuge uranium enrichment technology (centrifuges of the P-1 and P-2 types).

1989 Establishment of a secret team of IRGC scientists led by Dr. Mohsen Fakrizadeh under the cover of the AEOI and Tehran Sharif University.

1994-1999 Further negotiations between the IRGC-AEOI with Dr. Khan, as well as deliveries by him of gaseous centrifuge technology and sketches of the *Chic-4* device.

1995 Iran-Russia agreement on the construction of the LWR-class Bushehr Nuclear Power Plant.

1998 Series of nuclear tests by India and Pakistan, and the beginning of tests of the Shahab-3 short-range ballistic missile by Iran.

2000-2003 Top secret and most intensive work in the Amad Plan, i.e. M. Fakrizadeh's team on a nuclear warhead and other elements of Iran's nuclear arsenal.

2002 People's Mujahedin (armed opposition group) reveals Iran's covert nuclear facilities, i.e. pilot uranium enrichment plant in Natanz and heavy water production plant for a planned HWR IR-40 reactor in Arak.

2003 Decisions by Supreme Leader of Iran Ali Khamenei to halt work under the Amad Plan, reorganise it, and cover its traces before IAEA inspections, amidst Iran's nuclear talks with the EU3.

2004 German and U.S. intelligence obtains the "Laptop of Death" with files pertaining to the Amad Plan.

2006 Iran starts uranium enrichment in Natanz (3.5% LEU); the first package of UN economic sanctions against its nuclear and missile programmes is implemented.

2007	U.S. intelligence confirms the earlier decision to halt work on a nuclear warhead and tests under the Amad Plan. The U.S. joins the EU3 in talks with Iran.
2009	"Green Revolution" in Iran and the U.S. disclosure of a second uranium enrichment facility, underground, at Fordow.
2009-2011	Iran begins work on highly enriched uranium (20% HEU), Natanz facility is sabotaged in the Stuxnet cyberattack. Two special reports from the IAEA's long-term investigations confirms a "possible military dimension" in many elements and facilities of Iran's nuclear programme.
2012	U.S., EU, and UN sanctions on Iran escalate, including a ban on Iranian oil imports to Europe. The Bushehr Nuclear Power Plant starts operation and spent fuel returns to Russia regularly.
2013-2015	Iran engages in nuclear talks and makes interim agreement with the P5+1 group.
2015	Nuclear deal (JCPOA) introduces limits on the scale and scope of the Iranian programme in exchange for the lifting or suspension of the most severe sanctions by the U.S., EU, and UN.
2018	The U.S. withdraws from the JCPOA and announces a policy of "maximum pressure" on Iran. Iran increases the scale and level of uranium enrichment (now 60% HEU). Israeli intelligence intercepts the most secret files of the Amad Plan from Tehran.
2020	Assassination of Dr. M. Fakrizadeh, an alleged operation by Israeli intelligence.
2021	Iran suspends its obligations under the NPT Additional Protocol.
2022-2023	Nuclear talks between the U.S. and Iran are failing. More problems for the IAEA inspectors in Iran. The regime's military assistance to Russia begins, while volatile young Iranian anti-regime riots continue for five months.
2024	President Ebrahim Raisi dies in a helicopter crash. Masoud Pezeshkian wins the presidential election in the first round. Israel continues to escalate against the Iranian-led "Axis of Resistance" and two serious Iran-Israel military crises erupt, along with the collapse of the allied regime in Syria.
2025	The second Donald Trump administration takes over in January, with the likely resumption of the "maximum pressure" policy on Iran but also equally possible nuclear talks (*JCPOA-II*?).
20??	Issues of the succession of power after the death of Khamenei are resolved and the new leadership determines the future goals and scope of Iran's nuclear programme.

MILITARY NUCLEAR PROGRAMME OF IRAN: ITS HISTORY, SUSPENSION, AND PROSPECTS FOR THE FUTURE

Introduction

This report examines Iran's confirmed efforts in setting up the foundations of its nuclear arsenal and likely direction of future development. Given the dual-use nature of the entire nuclear fuel cycle, the division between the "civilian" or "military" dimensions or programmes is artificial and misleading, serving merely as a handy distinction. This report assumes that the military nuclear programme includes systemic works, from the acquisition of fissile materials to the assembly and production of nuclear weapons.[1] More complete definitions of the key concepts, terms, and jargon in the field of nuclear technologies are explained in the *Glossary* attached at the end of the report.

To simplify the issues at the intersections of policy, strategy, science, and technology, Iran, to develop a ready-to-use nuclear arsenal, needs to possess three key weapon elements (capabilities), which are:

(1) fissile material(s), which Iran can now process indigenously thanks to its existing facilities and industrial production of nuclear fuel;

(2) a device or weapon with a nuclear core based on highly enriched uranium or plutonium, which Iran was studying secretly up to 2003, and may produce in the future;

(3) operational nuclear warheads integrated and tested with selected means of delivery, along with Iran's likely preferred ballistic missile type.

Due to this narrow approach to the topic and this report's length limitations, the many changes in the rhetoric of the Iranian government, its methods of deception, the IAEA's reports and problems with these issues, and the changing international positions on Iran's nuclear potential are simply signalled or quickly mentioned. For the same reasons, this report briefly addresses the main issues of Iran's regional policy. The starting point is a short outline of Iran's ambitions and progress since 1974, followed by an outline of its covert Amad Plan, its equivalent to the Manhattan Project. After discussing Iran's potential as monitored by the IAEA, the main challenges that would prevent or accelerate a strategic decision to complete its nuclear arsenal are examined. Its existing and foreseeable means and systems of nuclear weapons delivery are also assessed. Separate sections are devoted to the main implications for Europe and recommendations for policies towards Iran.

The report is based on open sources, other experts' studies, the author's experience in the Polish foreign service and his and others' analytical work at PISM. However, the author has tried to avoid overloading it with academic literature on Iran's political culture and system, details of its scientific and technical intelligence collection, and any far-reaching theories about nuclear proliferation and nuclear strategies. The author also appreciates the comments on this work by other experts at various stages, while taking sole credit for any oversimplifications or mistakes.[2]

[1] In U.S. terminology, these two are reflected in the terms *nuclear weapons program* and *weaponisation process*.

[2] Apart from all colleagues at PISM, the author's extends special appreciation for consultations and comments by D.E. Krzysztof Król at the National Centre for Nuclear Research (NCBJ) in Świerk and Mr. Łukasz Kulesa, Director for Proliferation and Nuclear Policy at the Royal United Services Institute (RUSI) in London.

Evolution of Iran's Initial Nuclear Ambitions

The current nuclear programme of Iran is deeply rooted in the strategic ambitions displayed by the previous regime, i.e., before the Islamic Revolution. Similar to other Middle Eastern countries, Iran's motivation has been based on national security and prestige considerations. It is still debated whether Shah Reza Pahlavi intended for the military aims of the nuclear project to be hidden from the outset of his investments in Iran's scientific and industrial facilities, but this seems highly likely. Under his rein, Iran benefited from its vast oil reserves and high oil prices, which allowed the Shah to finance his ambitious plans for the modernisation of the state, society, and armed forces, as well as to build up its regional position and influence. Iran was clearly a beneficiary of U.S. scientific assistance provided since 1957 as part of the "Atoms for Peace" initiative. In the 10 years after joining the American initiative, the U.S. delivered a 5 MW light-water research reactor along with nuclear fuel (highly enriched uranium, HEU).[3] During the same period, Iran sent several thousand students and scientists to prestigious universities in the U.S. and Western Europe, launching research and development efforts that since 1974 have been officially coordinated by the civilian Atomic Energy Organization of Iran (AEOI).

Despite the close bilateral alliance with the U.S. at that time, Pahlavi's relations with the Gerald Ford and John Carter administrations were marked by numerous tensions, including over the intentions and scale of Iran's nuclear plans. In the mid-1970s, the Iranian monarch announced a plan to build as many as 23 reactors with a total power of 23,000 MW. Iran's ambitions were clearly aimed at mastering the full nuclear cycle, from mining natural uranium ore from the deposits at the Ardakan and Ghachine mines, to uranium enrichment on an industrial scale, and to developing various classes of nuclear reactors and facilities for plutonium reprocessing. In addition to Tehran, a few small centres, institutes, or departments of physics were established at universities. Pahlavi's comments after India conducted a series of "peaceful tests" did not escape the attention of the U.S. or Iran's neighbours. At that time, Pahlavi stated that Iran could acquire a nuclear arsenal "faster than it is commonly believed".[4]

Pahlavi's uncertainty about U.S. nuclear assistance, which continued but was periodically disrupted, led him to seek alternative partners in Western Europe and South Africa. As early as in 1974, Iran reached a preliminary agreement with the West German Kraftwerk Union to build a nuclear power plant in Bushehr on its Persian Gulf coast. The contract, signed in 1976 assumed the delivery of two 1,300 MW light-water reactors. By the time of the Iranian Revolution erupted, German engineers and technicians had completed 85% of the work necessary to start the first reactor, while work on the second was halfway complete. Towards the end of the Pahlavi monarchy, Iran also reached agreements with the French Eurodif consortium on future supplies of low enriched uranium (LEU) and with South Africa on the delivery of 600 tonnes of milled uranium ore concentrate (yellowcake).[5]

Revolutionary Iran abandoned all of Pahlavi's projects in 1979, but amidst the war with Iraq it regained interest in resuming the nuclear programme for military purposes. Grand Ayatollah

3 The U.S. research reactor foreseen for Iran was primarily intended for Iraq, but this plan was aborted after the 1958 coup in Baghdad and closer Iraqi-Soviet cooperation. In the end, Iraq received a Soviet IRT-2000 with 2 MW of power (LWR-class), which went critical in 1967. See: M. Braut-Hegghammer, *Unclear Physics: Why Iraq and Libya Failed to Build Nuclear Weapons*, Cornell University Press, Ithaca-London 2016, pp. 24-29.

4 Quotation from Pahlavi's interview for French *Les Informations* in June 1974. When this interview alarmed French journalists, the embassy of Iran in Paris (and likely on the Shah's instruction) published an official *dementi* of this passage. See: U.S. Embassy Paris, *Interview with Shah*, unclassified cable No. 15305, 24 June 1974, copy available at the George Washington University-National Security Archive, doc01a.pdf (gwu.edu).

5 For a good summary of Pahlavi's international efforts, see: A. Vaez, K. Sadjadpour, *Iran's Nuclear Odyssey: Costs and Risks*, Carnegie Endowment for International Peace, Washington DC 2013, pp. 4-6.

Ruhollah Musavi Khomeini, the founder and leader of the new Iranian theocracy, opposed the development of any kind of weapons of mass destruction. His initial policies resulted in the emigration or jailing of many talented scientists, who under the Shah enjoyed top salaries and privileges. The new regime's decision to cancel the previous contracts and agreements derailed cooperation with many of Iran's foreign partners. Nevertheless, the attrition and trench warfare with Iraq—during which the unfinished plant in Bushehr was repeatedly attacked and unfit for use for many years—changed the calculations of the new regime.

The systematic use of chemical weapons by Iraq and Iran accelerated covert efforts by both regional rivals to build nuclear arsenals. Officially, Iran resumed work on a civilian nuclear programme in 1985-1990, including experimental physics, power plant construction, and other dual-use technologies. At that time, Iran's efforts to revive scientific cooperation with a dozen or so countries were mostly transparent to the IAEA. The most far-reaching plans of cooperation were concluded with Argentina, Brazil, India, Italy, Pakistan, and the USSR. The most successful was bilateral cooperation with China, which, under the agreement signed in January 1990, delivered to Iran a 27 kW miniature neutron source reactor, a 30 MW research reactor and a (subcritical) training and teaching reactor. All three Chinese LWR-class reactors were delivered in 1992-1995 to the civilian centre in Isfahan. During the same period, Iran also negotiated with Argentina on planned nuclear fuel deliveries to the research reactor in Tehran.[6]

In 1986-1989, in parallel and in strict secrecy, Iran sought opportunities to deepen its knowledge and gain the technologies necessary to build nuclear weapons. It found these through its growing contacts in Pakistan and focus on the gaseous centrifuge method of uranium enrichment.[7] Influenced by the experience of the war with Iraq, Iran took its first steps in the development of a ballistic missile arsenal, taking advantage of initial assistance in this field from Libya and North Korea. These missiles were intended to compensate for the weakness of Iran's air force and to become the future means of delivery of its chemical weapons—and in the future, nuclear weapons too. After the death of the first Supreme Leader Khomeini in 1989, the overt and covert aspects of the nuclear programme gained the full support of his successor, Ayatollah Ali Khamenei. In addition to him, President Al Akbar Rafsanjani, his advisor Hassan Rouhani, then-Prime Minister Mir-Hossein Mousavi, and Gen. Mohsen Rezai of the Islamic Revolutionary Guard Corps (IRGC; its commander in 1980-1997) together played an important roles in preparing nuclear decisions and plans. This narrow group of decision-makers supported, supervised, and financed the entire covert military programme, jointly organised by officers of the IRGC and Ministry of Defence and Logistics. In April 1989, the programme, previously subordinated to the prime minister office and civilian AEOI, was formally transferred to the direct supervision of then-President Khamenei (and later, also President Rafsanjani).[8]

---

6 In 1992, Argentina terminated an agreement with Iran on further supplies of nuclear fuel and uranium ore. The end of prospective cooperation was also due to the IRGC's and Hezbollah's participation in the terrorist bombings of Israel's embassy in Buenos Aires that same year. On the civilian bilateral agreements, see: G. Gerardi, M. Aharinejad, "An Assessment of Iran's Nuclear Facilities," *The Nonproliferation Review*, vol. 2, no. 3, 1995, pp. 207-215, and A. Vaez, K. Sadjadpour, *op. cit.*, pp. 6-10.

7 On details of Pakistan-Iran cooperation, see: M. Fitzpatrick (ed.), "Nuclear Black Markets: Pakistan, A.Q. Khan and the Rise of Proliferation Networks—A Net Assessment," *An IISS Strategic Dossier*, London 2007, pp. 67-71; and F.H. Khan, *Eating Grass. The Making of the Pakistani Bomb*, Stanford University Press, Stanford CA 2012, pp. 363-368.

8 For an overview of Iran's work and problems with the project at that time, see: N. Gerami, "Iran's Strategic Culture: Implications for Nuclear Policy," in: J.L. Johnson et al. (eds.), *Crossing Nuclear Thresholds*, Palgrave-Springer Nature, Cham 2018, pp. 61-108; G. Samore (ed.), "Iran's Strategic Weapons Programmes: A Net Assessment," *An IISS Strategic Dossier*, London, September 2005, pp. 12-16; and A. Vaez, K. Sadjapour, *op. cit.*, pp. 6-10.

The early 1990s were characterised, on the one hand, by the slow progress of Iran's military programme and, on the other, by the still poor orientation and understanding of it by Western intelligence. This period was dominated by mostly unproven fears that the research reactor in Tehran and the planned nuclear power plant in Bushehr would be used by Iran to produce weapons-grade plutonium. These concerns were reflected also by usually inaccurate intelligence projections of its progress towards a nuclear weapon (within 5-10 years), which were regularly leaked to U.S. and Israeli media (see summary in Appendix 1). At that time, the concerns of the U.S. and Israeli governments were also related to the risks of fissile materials on the black market as well as expertise from post-Soviet countries. Estimates and public comments by officials in the Bill Clinton administration only later expressed (correctly) concerns about the scientific and technical assistance likely provided to Iran from China, Pakistan, and North Korea.[9]

Nevertheless, the U.S. efforts at pressure and persuasion were sufficient to limit Iran's nuclear cooperation with China, and to break or halt it with Argentina, India, Italy, and Spain, as well as with several countries in Central and Eastern Europe.[10] Equally successful have been the long-standing U.S. efforts to significantly limit Russia's cooperation with Iran, resulting in denied transfers of HWRs and technologies for reprocessing plutonium from the spent nuclear fuel from reactors to potentially produce weapons-grade plutonium. In August 1992, the governments of Russia and Iran signed agreement on nuclear cooperation. In January 1995, both also agreed on a plan to build a LWR-class VVER-100-type reactor producing 915 MW, foreseen for the nuclear power plant in Bushehr. However, in accordance with Soviet-era policy and to the additional and confidential U.S.-Russia arrangements, the Russian fuel spent during the entire period of this reactor's operations was to be returned from Iran.[11]

The Aims and Organisation of the Covert Amad Plan

In 1989, the Physics Research Centre was opened on the premises of Sharif University in a suburban area of Tehran (Lavizan-Shian). The centre concealed top-secret research and development works led from that time by Dr. Mohsen Fakrizadeh, a nuclear physicist and IRGC officer. Information reconstructed after 2002 confirmed that before the start of the nuclear weapons programme of Iran there were contacts with Dr. Abdul Qadeer Khan, head of the laboratory working on uranium enrichment for the military purposes of Pakistan. This scientist—likely without approval by the government of Pakistan—eventually sold the full documentation of crucial technologies for Iran to build a future nuclear arsenal.

Subsequent transfers of know-how from Khan's network to the IRGC were based on two separate negotiations and arrangements. The first phase took place in 1987-1992, and the second in 1994-1999. The "full package" from Khan included information on gaseous uranium enrichment technology, designs of cascades of P-1 and P-2 type centrifuges, a batch of used Pakistani centrifuges, and documentation of a proven Chinese warhead with a yield of 15-20

9 See also another overview of that period: A. Koch, J. Wolf, "Iran's Nuclear Procurement Program: How Close to Bomb?," *The Nonproliferation Review*, vol. 5, no. 1, 1997, pp. 123-134.

10 In some U.S. media and think-tank reports in the 1990s, there were suggestions that Iran attempted to buy some sub-parts of the aborted nuclear power plant project in Żarnowiec, Poland. However, the author for many years has been unable to confirm this revelation with any available Polish source.

11 A VVER-1000 reactor was constructed by the Russians in 1994-2009 and initially launched in May 2011, reaching full power in September 2012. Negotiations on this project were initiated by Iran *de facto* with the USSR in 1989. This and other Russian-Iranian projects were substantially curtailed by agreements between officials of the Bill Clinton and Boris Yeltsin administrations. For a good summary of nuclear issues in the U.S.-Russia-Iran triangle up to 2010, see: J. Carvelli, *Beyond Sand and Oil: The Nuclear Middle East*, ABC-CLIO, Santa Barbara CA 2011, pp. 95-99.

kt.[12] Still in the 1990s, the majority of Fakrizadeh's work was limited to a few small divisions of the Physics Research Centre, without any formal plans and structures to implement a military nuclear programme. The Iranian regime's decisions on this issue were withheld until 1998-2000 or 1999-2001, and there is still no available documentation to confirm all dates and details. However, it is almost certainly impossible that such a covert programme would happen without the clear approval or direction of Khamenei and Iran's Ministry of Defence and Logistics.

A reconstruction of the workings of the Amad Plan[13] in 2001-2003 testifies to Iran's highly ambitious and accelerated military programme at the time. It enjoyed the political support of the Supreme National Security Council and the Supreme Council for Science, Research and Technology. Moreover, it had the financial backing of the government, used the resources of the Ministry of Defence and Logistics, and the scientific and industrial facilities of the AEOI. Its key figure remained Fakrizadeh, who personally coordinated a number of separate subprojects, teams, and centres in several locations across Iran. Permanent elements of this programme, marked by frequently changed codes and cover names, included:[14]

A structure supervising all efforts—the so-called Orchid Office in Lavizan-Shian, officially and overtly part of the Sharif University campus.[15] Fakrizadeh's office was also responsible for liaising with the civilian AEOI and the Institute of Applied Physics, as well as with the Ministry of Defence and the command of the IRGC. The Orchid Office also instructed these institutions on purchases of dual-use equipment and materials abroad, legally or on the black market.

– **Work on obtaining uranium**, **both from foreign and domestic sources**. Attempts at clandestine purchases of the material in several countries failed, so the focus was on overt exploration and other efforts in Iran. Uranium ore was to be delivered from mines in the Saghand and Bandar Abbas areas, while processing of the ore was handled by a facility in Ardakan and its further conversion by plants in Isfahan and Tehran (all formally subordinate

12 It was implosion device modelled on the Chinese Chic-4, and China conducted its first test in the autumn of 1966 with the flight of a Dong Feng-2 MRBM. In 1982 or 1983, China transferred documentation about this nuclear warhead to Pakistan. Pakistan's first warhead may have been identical to Chic-4, as was the device used in North Korea's failed Kim-1 nuclear test in October 2006 (likely foreseen as a warhead for No Dong-1 MRBMs). For information and assessments by a former U.S. Department of Energy intelligence analyst, see: Th.C. Reed, D.B. Stillman, *The Nuclear Express. A Political History of The Bomb and Its Proliferation*, Zenith Press, Minneapolis MI 2009, pp. 128-129, 250-266. The issues of China-Pakistan nuclear cooperation were known to the U.S. intelligence but clearly marginalised by the importance of trilateral cooperation on Afghanistan. For more on the political context at that time, see: D. Kux, *The United States and Pakistan 1947-2000*, John Hopkins University Press, Baltimore MD 2001, pp. 259-261, 295-311, 321-334.

13 The Persian name of the "Amad Plan" can be translated in a number of ways, including as the "Readiness Plan" (preferred by the author, but not used in the main text), the "Future Project," the "Organisation Plan," or the "Possession Project". In IAEA materials and in media, its name is erroneously written as an acronyms, i.e., the AMAD Plan.

14 The discussion of the structure of the Amad Plan draws on findings from subsequent IAEA reports: *Implementation of the NPT Safeguards Agreement and Relevant Provisions of Security Council Resolutions 1737 (2006), 1747 (2007), 1803 (2008) and 1835 (2008) in the Islamic Republic of Iran*, IAEA, Vienna 16 November 2009; *Implementation of the Safeguards Agreement and Relevant Provisions of Security Council Resolutions in the Islamic Republic of Iran*, IAEA, Vienna 8 November 2011, and *Final Assessment on Past and Present Outstanding Issues Regarding Iran's Nuclear Programme*, IAEA, Vienna 2 December 2015. An important addition to these is the disclosed archival files of the Amad Plan, obtained in early 2018 by Israeli intelligence. See: A. Arnold, et al, "The Iran Nuclear Archive: Impressions and Implications," *Intelligence & National Security*, vol. 36, no. 2, 2021, pp. 230-242, and D. Albright, O. Heinonen, A. Stricker, *Breaking Up and Reorienting Iran's Nuclear Weapons Program. Iran's Nuclear Archive Shows the 2003 Restructuring of its Nuclear Weapons Program, the called the AMAD Program, into Covert and Overt Parts*, Institute for Science and International Security-Foundation for Defense of Democracies, Washington DC, 29 October 2018.

15 From Orchid Street in one of Tehran's suburban neighbourhoods, where the Amad Plan management functioned on a daily basis.

to the AEOI). At that time, equally secret was the work on the pilot uranium enrichment plant in Natanz, and later in the larger and naturally protected facility at Fordow. The first one was revealed in the summer of 2002[16] and the latter in the autumn of 2009, which after their cover was blown were subordinated to the AEOI. The role of the Jabir Ibn-Hayyan laboratory and the nature of its work under the Amad Plan are not fully clear, but it was likely foreseen as the location for experiments with various forms of uranium.

- **Work on nuclear weapons, their testing and production (Project No. 110)**. According to the original and rather optimistic plan, the construction of five implosion-type warheads was to be completed by mid-2003.[17] Available documents and IAEA inspections have so far not clarified if and when Iran intended to test its first nuclear device. The larger Project 110 team at the Parchin site was likely to produce the metallic cores of the warheads using materials from Natanz and Fordow.[18] The construction of devices and warheads was tasked to several teams and subgroups, including those making calculations and theoretical models, computer simulations, testing of conventional explosives and multi-point detonators[19], neutron initiators, and so-called cold tests (planned for spring 2003). Outside Tehran, separate groups of scientists and experts were involved in selecting and reviewing potential sites for a nuclear test (2001-2002), and then preparing an underground tunnel for a nuclear test and measurement facilities at a training ground in the Seman desert (2002-2003).[20]
- **Integration of the warhead and its re-entry vehicle into a ballistic missile (Project No. 111)**. According to the Amad Plan, Iran chose the Shahab-3 missile, a modification of North Korean No Dong-1, as the means of delivery of a nuclear warhead. At that time, the missile was already in the testing phase with conventional warheads, conducted by the IRGC. Project 111 was led by one larger team responsible for studies, concepts, sketches and simulations, as well as for designing the re-entry vehicle for the warhead. At a later stage, the developed and assembled warhead prototype was to be integrated with the Shahab and to be tested in flight.[21] There is no information about the specific date for the planned missile or other tests, but presumably it could have been in 2003-2004.

At the same time as the consolidation of the Amad Plan, there were breakthroughs in identifying, penetrating, analysing, and making public some elements of Iran's covert programme.

[16] In summer 2002, the heavy water production facility for the IR-40 reactor at Arak was also revealed. This indicated Iran's intention to achieve weapons-grade plutonium production in the future, so to be obtained in parallel or shortly after producing weapons-grade uranium.

[17] As indicated earlier, Iran's design of an implosion-type warhead was based on the Chic-4 model plans sold by A.Q. Khan.

[18] Also under the code and cover names of Project No. 5 and the Boroujerdi Martyr Project. For details, see: D. Albright et al, *A Key Missing Piece of the Amad Puzzle: The Shahid Boroujerdi Project for Production of Uranium Metal and Nuclear Weapons Components*, Institute for Science and International Security-Foundation for Defense of Democracies, Washington DC, 11 January 2019.

[19] The team also under the codename Project No. 3 and cover name Project Marivan. For multi-point detonators and material compression, Iran was assisted by Vyacheslav Danilenko, a Ukrainian citizen and former expert at the NII-1011 (Chelyabinsk) centre, where nuclear warheads for the USSR were designed and produced. See: J. Borger, "Iran nuclear report: IAEA claims Tehran working on advanced warhead," *The Guardian*, 7 November 2011, and J. Warrick, "Russian Scientist Vyacheslav Danilenko's Aid to Iran Offers Peek at Nuclear Program," *The Washington Post*, 13 November 2011.

[20] All the work of these teams was codenamed Project Midan" and the nuclear device codenamed Sareb-1. For more details, see: D. Albright et al., *Project Midan: Developing and Building an Underground Nuclear Test Site in Iran*, Institute for Science and International Security-Foundation for Defense of Democracies, Washington DC, 2 April 2019.

[21] In later files, the Project 111 has the codename Sareb-2 for the re-entry vehicle and Sareb-3 for the missile integrated with a warhead. In addition to the three IAEA reports, see also: D. Albright, O. Heinonen, A. Stricker, *The Plan: Iran's Nuclear Archive Shows It Originally Planned to Build Five Nuclear Weapons by mid-2003*, Institute for Science and International Security-Foundation for Defense of Democracies, Washington DC, 20 November 2018.

Chronologically, these were first the discovery and dismantling of the A.Q. Khan network by the UK and U.S. intelligence (2001-2002). Information about the activities of this network was presumably passed to Israel, allowing it to reveal in 2002 (via the opposition People's Mujahedin) facilities unknown to the IAEA, including the uranium enrichment plant at Natanz and heavy water production plant at Arak. Details identifying Fakrizadeh's coworkers and the scope of their work were also provided by files from one of his subordinate teams obtained by German intelligence and the CIA in 2004. The contents of a computer with a dossier (the so-called laptop of death) confirmed, among other things, clear similarities between the nuclear technologies of Pakistan, Iran, North Korea, and Libya. These files allowed further technical analysis by scientists at the Oak Ridge and Los Alamos laboratories, U.S. Department of Energy intelligence divisions, and at the CIA. In subsequent years, the results of these analyses significantly facilitated IAEA inspectors' investigations in Iran.[22]

Halt of the Amad Plan and Iran's Nuclear Negotiations

After Iran's military nuclear programme was revealed in the summer of 2002, the authorities obliterated its traces and halted Amad Plan in the autumn of 2003. Revelations published in August 2002 by the Iranian opposition on the installations at Arak and Natanz placed the entire nuclear programme among the most urgent issues for the IAEA and the UN.[23] Iran denied the previous subordination of these facilities to the Ministry of Defence, quickly transferring them along with some scientists to the civilian AEOI structures. The disclosure of the uranium enrichment plant also forced the reorganisation of key teams subordinated to Fakrizadeh, and the full destruction of the Lavizan-Shian centre buildings. Iran also delayed clarifying new questions raised by the IAEA. For international and domestic reasons, it made the right to enrich uranium a prestige issue. However, it accepted the IAEA's demands and the first proposals of the EU3 group (France, Germany, and the UK) to suspend work at Natanz. To the surprise of the agency's inspectors and European diplomats, substantive talks with them had been held since autumn 2003. But these were led not by the head of Iran's Foreign Affairs Ministry or the AEOI, but by Hassan Rouhani, secretary of the Supreme National Security Council of Iran. In December 2003, Iran also agreed to sign the Additional Protocol to the NPT.[24]

Khamenei's decision in the autumn of 2003 to halt the military programme was presumably consulted with a similar group of people as when it was initiated.[25] Despite a lack of details of their internal discussions or secret decisions, their context and strategic rationale are clear. At that time and above all, Iran's ruling elite feared that it would be the next U.S. target after

22 The P-1 centrifuges and documents handed over by Libya to the U.S., easing later reconstruction of the IR-1 installations in Iran, and the U.S.-Israeli Stuxnet cyberattacks on the computers controlling these. For more about the "Olympic Games" operation against the Natanz and Bushehr centres, see: D.E. Sanger, *Confront and Conceal: Obama's Secret Wars and Surprising Use of American Power*, Crown Publishing Group, New York 2013, pp. 188-225, and Y. Katz, Y. Hendel, *Israel vs. Iran. The Shadow War*, Potomac Books, Washington DC 2012, pp. 101-105.

23 In August 2002, both sites were revealed to media by the National Council of Resistance of Iran (NCRI), which is a front organisation of the People's Mujahedin (MeK, *Mujahedin el-Khalk*) movement in the West.

24 The Additional Protocol significantly expands the IAEA's powers in verifying the safeguards foreseen by the treaty.

25 The president during this period was the "reformist" Mohammad Khatami (1997-2005), who certainly oversaw the budget issues of the Amad Plan. However, it is questionable whether his views on security policy issues were influencing Khamenei, Rouhani, and the IRGC at the time. See the excellent summary of informal influence groups and decision-making processes in Iran by A.W. Samii, "The Iranian Nuclear Issue and Informal Networks," *Naval War College Review*, vol. 59, no. 1, Winter 2006, pp. 63-90. On the formal structures and processes, see: K. Lim, "National Security Decision-Making in Iran," *Comparative Strategy*, no. 34, 2015, pp. 149-168.

the overthrow of Saddam Hussein's regime in Iraq. The intervention in Iraq was justified by the White House on the basis of Iraq's alleged continuation of its weapons of mass destruction programmes, and that forced Iranian decision-makers to review similar indigenous projects. President George W. Bush's rhetoric on the elimination of the "Axis of Evil" was very credible with the steadily surging U.S. military presence in Afghanistan and Iraq.[26] Iran's decision in 2003 was unlikely to have been influenced by the issue of Libya's nuclear programme because, at that time, the Libyan nuclear negotiations were still conducted in strict secrecy.[27] However, Libya's emergence from international isolation and its cooperation with the IAEA at the end of 2003 must have reinforced Iran's conviction that it would be profitable to continue nuclear talks with the Europeans, and later with the Americans. In this context, Iran may have additional concerns that cooperation between the superpowers on further countering international terrorism and the proliferation of weapons of mass destruction may become a sustainable trend. Despite the announced Iran-Russia "strategic partnership", it may have seemed to the Iranians that U.S.-Russia pragmatic relations are more viable and likely. Moreover, when Fakrizadeh's teams were halted and reorganised, Iran's partnership with China did not yet have an explicit anti-U.S. dimension. Thus, Khamenei and his advisors may have assumed then that Iran's relations with Russia and China would not secure their support in a nuclear dispute in UN Security Council discussions on far-reaching multilateral sanctions.[28]

Iran's decision in the autumn of 2003 to suspend work on its nuclear arsenal was secret, and was only confirmed by U.S. intelligence and IAEA inspectors in 2007-2009. In late 2007, the Bush administration, after receiving of a new intelligence assessment of the Amad Plan, was forced to publish an unclassified summary of its conclusions.[29] The findings of the newest National Intelligence Estimate were controversial, mainly the key thesis on the need to halt Fakrizadeh's work. There were doubts outside the U.S. administration about the intelligence sources and evidence, impartiality, or even the competence of the authors and editors of the NIE text. Some of the allegations stemmed from a lack of critics' access to the full text of the 140-page top-secret report, but most from a misunderstanding of its unclassified conclusions, the terminology used, and the intelligence methodology (see details of the NIE in Appendix 2).[30]

---

[26] G.W. Bush first used the term the "Axis of Evil" in his State of the Union Address in January 2002, characterising North Korea, Iraq, and Iran: President Delivers State of the Union Address (Text Only) (archives.gov). During this period, an additional source of tension between the U.S. and Iran was the fact that several members of Osama bin Laden's family and Al-Qaeda leaders were under IRGC "house arrest" in Tehran. For details on their relationship, see, e.g.: D. Byman, "Unlikely Alliance: Iran's secretive relationship with al-Qaeda," *Jane's Intelligence Review*, no. 7, July 2012, and B. Loidolt, "Al-Qaeda's Iran Dilemma: Evidence from the Abbottabad Records," *Studies in Conflict and Terrorism*, vol. 46, no. 5, 2023, pp. 513-540.

[27] Tripartite talks began in 1999, while the final phase of negotiations with Libya started in early 2003. In October, the U.S. seized a ship with centrifuges bound for Libya. The agreement with Libya was revealed in December 2003. For details of the negotiations, see: M. Braut-Hegghammer, *op. cit.*, pp. 210-217.

[28] Iran's nuclear and missile programmes were the justification for further sanctions by the UN Security Council Resolutions of December 2006 (UNSCR 1737), March 2007 (UNSCR 1747), March 2008 (UNSCR 1803), September 2008 (UNSCR 1835), and June 2010 (UNSCR 1929). In addition and under UNSCR 1929, a UN Panel of Independent Experts for the monitoring of the two Iranian programmes was in operation in 2010-2016.

[29] Regardless of the attitudes of the consumers of the classified and unclassified versions of the NIE, it was clear that U.S. intelligence remained under the shadow of failed estimates of Iraq's weapons of mass destruction. Moreover, President Bush concluded that it was inevitable that new findings on Iran would be leaked to media, so decided it was better to publish an unclassified summary of them. These issues were discussed and confirmed by the author in conversations with U.S. National Security Council officials, Washington DC, December 2007, January and February 2008.

[30] The CIA in the spring of 2007 acquired new information about Fakrizadeh's work and the intentions of the Iranian regime, resulting in the rejection of the first and then ready version of the NIE. This caused work on a new text of the NIE for the next six months. For more on the methodology and conclusions of the report, see: V.H. Van Diepen, "Reevaluation the 'Externals' and 'Internals' of the 2007 Iran Nuclear NIE," *Intelligence & National Security*, vol. 36, no. 2, 2021, pp. 176-207 (the author of this paper was the coordinator and editor of the text of the "nuclear NIE").

However, most of the criticism in late 2007 and early 2008 of the U.S. intelligence community came from Republicans and their expert base, traditionally sceptical of it. The Bush administration itself perceived the NIE's conclusions as sensationalist and as damaging efforts to control and limit Iran's overall nuclear capabilities. Some U.S. allies used the NIE report's conclusions as support for diplomatic solutions and subverting the idea of preventive strikes on Iranian nuclear facilities. The publication of the unclassified summary of the NIE report was also met with almost open frustration by the government of Israel. Its disappointment was also clear with the publication of successive IAEA reports about the results of its investigations into key elements of Iran's military programme. Moreover, even archives of the Amad Plan obtained by Israeli intelligence and published in 2018 did not show the continuation of military efforts after 2003.[31] Nevertheless, in parallel with the already halted military research and development, Iran continued to enrich uranium at Natanz, and years later at Fordow. Limiting the scale and level of uranium enrichment became the main topic of Iran's more than a decade nuclear negotiations, first with the EU3 and later with the P5+1 group.

In the summer of 2015, Iran agreed to limit its civilian programme as part of the nuclear deal (JCPOA). But in May 2018, the nuclear agreement was terminated by the U.S., in line with Trump's earlier statements. For the Iranian regime, the JCPOA negotiations took place in an already changing domestic and international context. They were preceded by the "Green Revolution" in Iran and the revelation of the second uranium enrichment plant at Fordow in 2009 (it had been officially operational in 2011) and the commissioning of Iran's first nuclear power plant in Bushehr (it has been operational at full capacity since 2012, with Russia receiving spent nuclear fuel), and above all, of the increasingly severe U.S., EU, and UN sanctions on Iran. The negotiation of the deal was facilitated by Khamenei's acceptance to Iran's talks with the P5+1 and the presidency of Hassan Rouhani.[32] The JCPOA was primarily a compromise between the Barack Obama administration and Iran, although EU diplomacy also played substantive technical and economic roles.

The essence of the JCPOA was the lifting of U.S. and international sanctions over Iran's nuclear programme in exchange for limits and full control of its scope. Iran pledged, among other things, to limit its uranium enrichment to 3.67% level for 15 years, to reduce its stockpile of LEU to 300 kg for 10 years, to limit research and development of the advanced centrifuges, and not to produce heavy water and use HWRs for 15 years.[33] The agreement also stipulated the conversion of the IR-40 reactor at Arak from HWR- to LWR-class by Chinese experts (this reactor remained unfinished anyway in 2015). With Russia receiving spent fuel from the Bushehr plant, the all agreed steps practically ruled out Iran's ability to produce weapons-grade

[31] The IAEA reports from 2009, 2011, and 2015, taken together with U.S. and Israeli intelligence documents, provide detailed documentation of Iran's military projects. This all confirmed the halt or suspension of Iran's nuclear weapon development in 2003. However, some experts who had direct access to the files stolen by Mossad indicate the possibility of the continuation of the military programme in 2003-2009. Israel's government has so far failed to prove the veracity of this suggestion. For arguments on continuation, see: D. Albright, O. Heinonen, A. Stricker, *Breaking Up and Reorienting...*, pp. 2 and 23. The contradictory arguments about the halt or some continuation of the covert programme since 2003 could only be resolved by Iran's full cooperation with the IAEA.

[32] Rouhani's predecessor was Tehran's secular mayor Mahmoud Ahmadinejad, a two-term president (2005-2013) who was very publicly active in the nuclear dispute. Like Khatami, he does not seem to have had strong influence in shaping the programme and negotiations. Despite his support from Khamenei during the "Green Revolution" in 2009, towards the end of his second term he later came into conflict with the Supreme Leader, as well as parts of the clergy and the IRGC.

[33] Full text of the JCPOA and all its annexes: https://www.europarl.europa.eu/cmsdata/122460/full-text-of-the-iran-nuclear-deal.pdf.

plutonium for warhead cores (see also the summary of main points in Appendix 3).[34] Moreover, the JCPOA provided an end of the embargo on the transfers to Iran of conventional weapons in 2020 and technologies or components for ballistic missiles in 2023.

Trump's first administration revived and expanded the U.S. sanctions after the termination of the agreement, and Iran has been progressively moving away from its JCPOA commitments since May 2019. In the view of Trump and the majority of the U.S. Congress, the flawed nature of the deal was not due to the focus on detailed technical issues, but primarily due to the failure to address remaining problems in U.S.-Iran relations and regional issues.[35] However, and contrary to numerous opinions published in the summer of 2015, the JCPOA was never foreseen or accompanied by any informal or secret arrangements on regional issues, Iran's resignation of its support for terrorism or the stop in its missile programmes.

The nuclear deal of 2015 significantly and temporarily eased tensions around Iran, but it never guaranteed its strategic compromise with the U.S. Its large text focused exclusively on the limits of Iran's nuclear capabilities. The Obama administration's fundamental goal was to rule out rapid enrichment of uranium above the 20% level and the scenario of assembling the first uranium core nuclear warhead faster than 9-12 months (i.e., extending or slowing down *breakout time*).[36] This gave the U.S. time to prepare its own and an international response to such an eventual scenario. Despite repeated attempts by the Joe Biden administration and EU diplomacy, the West has failed to convince Iran to renew the deal. Iran presents a rigid position on sanctions and any new annexes to the JCPOA, although each time in the talks it stresses the reversibility of uranium enrichment to the 20% level.[37] Iran's inflexibility vis-à-vis the U.S. and the EU might be also explained by the reorientation of its trade to Asia and the self-reliance attitudes of Khamenei and the President Ebrahim Raisi.[38] The overall situation of Iran was

[34] Some physicists question the relevance of these and argue that LWR-class (like HWR) could produce reactor-grade plutonium for the core of a nuclear weapon. This thesis is based on a U.S. experiment with reactor-grade plutonium and a nuclear test in 1962. In the author's opinion, Iran would face problems with this solution, which would be difficult to overcome quickly without several decades of experience. For more on the ever-present risk of Iran using LWRs and future HWRs to produce reactor- and weapons-grade plutonium, see: G.S. Jones, *Iran's Bushehr Nuclear Power Reactor: A Potential Source of Plutonium for Nuclear Weapons*, Nonproliferation Policy Education Center, Arlington VA, 24 March 2016, and *The Plutonium Pathway: Arak Heavy Water Reactor and Reprocessing*, Institute for Science and International Security, Washington DC, 27 July 2015.

[35] For a summary of the problems surrounding the JCPOA and Donald Trump's first presidency, see: International Crisis Group, "The Iran Nuclear Deal at Six: Now or Never," *International Crisis Group Report*, no. 230, 17 January 2022.

[36] The host of variable factors (current stocks, levels of enrichment, loss in part of uranium, type, variants and number of centrifuges, and the number of cascades) prevents here a presentation of the different calculations for Iran's *breakout time*. A few experts regularly update such calculations and are quoted in the text, but their estimates are subject to a wide margin of error. The minimum time for *breakout* should not be confused with the minimum quantity of fissile material (*significant quantity*, *SQ*) or the actual time necessary for the assembly of the operational warheads with their integration with means of delivery (or full weaponisation). For good backgrounders on this, see: D. Butler, "Iran Nuclear Deal Poses Scientific Challenges," *Nature*, 9 April 2015, www.nature.com, and E. Kam, E. Asculai, "Countdown to the Iranian Bomb," *INSS Strategic Assessment*, vol. 12, no. 4, February 2010, pp. 7-20.

[37] With the gas-centrifuge enrichment method, it is also possible to perform downblending ("dilute") on the uranium purity, such as from 60% to 20% HEU or 19% to 5% LEU. For Iran, this is also a good option to manipulate the IAEA's and Western concerns by, on the one hand, threatening the capability of rapid production of HEU up to 90% (i.e., weapons-grade uranium) and, on the other hand, showing the possibility of a quick return to "harmless" LEU of 3% or 5%. For more about the parameters and performance of Pakistani and Iranian centrifuges, see: A. Glaser, "Characteristics of the Gas Centrifuge for Uranium Enrichment and Their Relevance for Nuclear Weapon Proliferation," *Science and Global Security*, vol. 16, no. 1-2, 2008, pp. 1-25, and H.G. Wood, A. Glaser, R. Scott-Kemp, "The Gas Centrifuge and Nuclear Weapons Proliferation," *Physics Today*, no. 9, September 2009, pp. 40-45.

[38] Raisi was a Shiite cleric who unsuccessfully ran in the 2017 presidential election as Rouhani's rival. He took up the post after the 2021 elections and died in a helicopter crash in May 2024.

further complicated by the massive and intense popular protests in autumn 2022-spring 2023, at the scale going far beyond what has been seen during the "Green Revolution" of 2009.

Iran's Current Capabilities of the Nuclear Programme

Full verification of Iran's nuclear capability is currently impossible because of its suspension of its obligations under the JCPOA and the NPT Additional Protocol. In particular, there is less and less access of IAEA inspectors to all enrichment-related sites, although they continue to have access to all operating reactors. Meanwhile, there is a growing list of actions or inactions on Iran's side that are of concern to the agency. Since February 2021, Iran has prevented the IAEA from monitoring the country's production and stockpiles of heavy water, visiting some of its facilities, access on any day to uranium enrichment facilities, and verifying the work and types of gas centrifuges. Since June 2022, Iran has escalated the situation by removing cameras and other monitoring equipment, thus creating gaps in IAEA knowledge. Since September 2023, Iran has also refused visas and permissions for some of the agency's most experienced inspectors.

IAEA quarterly reports (June and August 2024) on Iran's implementation of the NPT Additional Protocol indicate that there are various unresolved problems:[39]

- no explanation for traces of uranium of unnatural origin at the Veramin and Turquz-Abad sites;
- no information on the construction plans and core design of the new 360 MW IR-360 reactor to be built at Darkhovin (originally planned to be built by 2011);
- inconsistent data on the yellowcake conversion facility in Isfahan;
- inconsistent data on waste following experiments at the previously decommissioned Lavizan-Shian laboratory.

A separate IAEA quarterly report (November 2024) also indicates that Iran's total enriched uranium stockpile has not been verified since February 2021. The agency—now relying mainly on its own estimates—puts Iran's stockpile of uranium of various forms at almost 6 tonnes. The agency's detailed estimates for end of October were as follows:[40]

- 2,190 kg of low enriched uranium 2% (539.9 kg more in this form in three months);
- 2,594.8 kg of low enriched uranium 3-5% (273.3 kg more in this form during the period);
- 839.2 kg of low enriched uranium 20% (an additional 25.3 kg for the quarter);
- 182.3 kg of highly enriched uranium 60% (stock increased by 17.6 kg during the quarter).

According to non-government estimates, Iran's total fissile material capabilities and stockpiles already allow it (if it chooses to so) to build the foundations for a nuclear arsenal (reaching *breakout time*). A group of well-recognised experts calculate on the basis of the above IAEA data that Iran—in transition from 60% to 90% highly enriched uranium—could:[41]

---

[39] Cf. *Safeguards Agreement with the Islamic Republic of Iran*, IAEA, Vienna 5 June 2024 and 29 August 2024, available with other IAEA quarterly reports at: IAEA and Iran - IAEA Board Reports | IAEA.

[40] Cf. *Verification and monitoring in the Islamic Republic of Iran in light of United Nations Security Council resolution 2231 (2015)*, IAEA, Vienna 19 November 2024, pp. 8-9 and 11. Electronic copy available at IAEA as above.

[41] For details of these calculations, see: D. Albright et al, *Analysis of IAEA Iran Verification and Monitoring Report*, Institute for Science and International Security, Washington DC 21 November 2024, pp. 1, 14-15, https://isis-

– within a week assemble the core of the first nuclear device;[42]

– within a month gain cores for 10 warheads;

– within two months gain cores for 13 warheads;

– within three months gain cores for 14 warheads;

– within four months gain cores for 15 warheads;

– and within five months gain cores for 16 warheads.

The above data and projections mean that Iran, after the termination of the JCPOA, has already and repeatedly exceeded the IAEA's criteria of *significant quantities* of fissile material for assembly of an arsenal and to conduct its first nuclear test.[43] Iran having these technical capabilities is thus able to relatively quickly assemble a nuclear arsenal of 15-16 warheads, i.e., three times more that assumed in the Amad Plan. Importantly and currently, U.S. intelligence estimates that Iran has not resumed works on building its first nuclear device, the serial production of warheads, or acquiring an operational arsenal. In this regard, all annual and unclassified estimates by U.S. intelligence directors (the most recent in March 2024) include caveats with almost identical language that Iran could build a nuclear weapon if it chose to do so.[44] Such a categorical conclusion about the lack of active work on weaponisation could not be made by a professional intelligence service without a solid basis. The accuracy of this kind of analyses always depends on the reliability of the sources of information, the effectiveness of the methods used to obtain them, and—and last but not least—the competencies of the intelligence analysts. It cannot be entirely ruled out that this estimate is flawed if the U.S. and its partner intelligence services have lost informers or are reproducing outdated knowledge.[45] However, as media leaks during the first Israel-Iran military crisis in spring 2024 suggest, it is more likely that the CIA retains sensitive and well-placed human intelligence sources in Tehran.[46]

Scenarios for Assembling Iran's Nuclear Arsenal

For many years to come, Iran's currently declared and monitored nuclear facilities are not capable of ensuring sufficient plutonium for its nuclear arsenal. Moreover, the use of any of

online.org.

42 A distinction must be made here between a nuclear device intended for testing and the final model of an operational warhead (for serial/mass production) based on a tested device. An illustration of this difference can be found in the "Gadget-Trinity" test in New Mexico and a derivative of its design in the Fat Man bomb the U.S. dropped on Nagasaki.

43 According to the IAEA definition, a "significant quantity" (SQ) is the minimum amount of material required to build a single nuclear warhead of simple design: 25 kg of highly enriched uranium (above the 20% level), 75 kg of low enriched uranium, 10 tonnes of depleted uranium or 8 kg of weapons-grade plutonium. Cf. *International Atomic Energy Agency Safeguards Glossary 2001 Edition*, IAEA, Vienna 2002, p. 23.

44 *Annual Threat Assessment of the U.S. Intelligence Community*, Office of the Director of National Intelligence, Washington DC 11 March 2024, p. 19, https://www.odni.gov.

45 With these types of arguments, they often come from the same U.S. and Israeli experts as with the summary of the "Iran NIE" of 2007.

46 In the March-April period of this year, information about plans for a missile attack on Israel was leaked to media, in the author's view indicating the level of intelligence penetration of Khamenei's entourage and the IRGC command. In contrast, U.S. assessments of Iran's nuclear capabilities suggest deep penetration of AEOI and IRGC facilities and research centres. For more on the run-up to Iran's missile attack on Israel, see: M.J. Lee, J. Hansler, *U.S. Preparing for Significant Iran Attack on U.S. or Israeli Assets in the Region as Soon as Next Week*, CNN, 5 April 2024, https://edition.cnn.com, and E. Schmitt, F. Fassihi, "Iran Likely Will Strike Israel, Not U.S. Forces, U.S. and Iranian Officials Say," *The New York Times*, 12 April 2024.

Iran's reactors for obtaining weapons-grade plutonium makes them easy targets for airstrikes by Israel or the U.S. Even with the official and final denunciation of the JCPOA, Iran on its own is still unlikely to build the necessary reactors and plutonium reprocessing or separation facilities quickly. The development of a well-concealed HWR in Iran can be almost completely ruled out. The operational LWR-class reactors in Bushehr, Isfahan, and Tehran pose little risk of rapid adaptation to military goals. The announced construction of a medium-power and new IR-360 reactor in another nuclear power plant, due to technological and financial barriers, will likely not be completed earlier than by the declared date of 2030. The scenario of the Iran importing an operational HWR-class reactor or large quantities of weapon-grade plutonium seems very speculative. Indeed, at present only North Korea has sufficient experience with the covert—but unsuccessful—construction of a graphite-uranium reactor in Syria. However, detection by the U.S. or Israeli intelligence seems technically possible and likely at the early stage of construction of one in Iran (as it was in the case of Syria).[47]

In contrast, following the general decision by Iran to build a nuclear arsenal, its industrial base allows for now only the "uranium pathway". From strategic and technological points of view, three scenarios can be considered, although an assessment of their probability must consider additional political factors on Iran's side (see details in the next section). The three most general directions available to Iran are described by experts as *creep out*, *breakout*, and *sneak out*:[48]

- *Creep Out*—**Iran is mastering uranium enrichment capabilities and resources but with IAEA monitoring**. In fact, Iran has already been pursuing this course since the U.S. exit from the nuclear deal in 2018. By continuing it, Iran is strengthening its negotiating position and creating uncertainty about its intentions, while making it more credible with periodic obstruction or denial of IAEA monitoring.[49] In this scenario, Iran is still fully free to choose between its current fissile material stocks for a future arsenal, from assembly to testing and the production of nuclear warheads. In doing so, Iran may assume that the greater its capacity and stockpile of uranium enriched to 60%, the greater concessions it will gain from the U.S. and Europe on economic sanctions. In that case, a larger stockpile of uranium in this form would also have a deterrent value for Iran as a kind of "virtual nuclear arsenal". This is made more credible without the actual assembly of warheads, their testing, or future serial production. It is forcing the U.S. to assess the rationale for a military strike to prevent the assembly of warheads and the build-up of a viable nuclear arsenal. Iran could present to the IAEA a variety of justifications for civilian nuclear fuel for atomic energy necessary for its ever-increasing domestic needs for electricity.[50] Therefore, Iran's abiding by the NPT

[47] In 2001-2007, Syria and North Korea worked on the construction of a 5 MW reactor at al-Kibar (actually Dair Al-Zour). U.S. and Israeli satellites had been tracking this in Syria since 2005, and images of the interior of the reactor's hall were obtained by Israel in early 2007. Israel successfully bombed the reactor in September 2007. Based on available sources, it is difficult to conclude whether the Syrian project was carried out with the participation or some assistance of Iran. For a comparison of the U.S. intelligence materials and IAEA final investigation on this, see: *Background Briefing with Senior U.S. Officials on Syria's Covert Nuclear Reactor and North Korea's Involvement*, Office of the Director of National Intelligence, Washington DC, 24 April 2008, https://www.odni.gov, and *Implementation of the NPT Safeguards Agreement in the Syrian Arab Republic*, International Atomic Energy Agency, Vienna 24 May 2011, https://www.iaea.org.

[48] In this paragraph, the author was inspired by the earlier projections and analysis (but technical parameters have changed) by G. Samore, "How Close Is Iran to the Bomb? The Limits of Nuclear Breakout," *Middle East Brief*, no. 149, Brandeis University, Waltham MA August 2022, pp. 4-6.

[49] Manipulation of access by IAEA inspectors might be repeated again and again, every time raising Western concerns and forcing minor concessions from the agency or Europe.

[50] A good excuse by Iran here would be to announce a plan for the construction of a large power plant or nuclear-powered oceanic ships. Such plans were already presented by Iran during the period of the first talks with the P5+1. All plans and schedules might be another bluff by Iran, but some Western governments will probably take them as arguments for continuing the political dialogue and nuclear negotiations with Iran.

may be important enough for the majority of the EU countries to continue negotiations with Iran on its return to the JCPOA and suspension of sanctions. This scenario also allows Iran to manage the tensions with the U.S. and Europe over the long term. Iran could negotiate limited or interim agreements on specific restrictions on uranium enrichment and production. Only uranium enriched to the 90% level (weapons-grade uranium, WGU) would be unacceptable to the U.S. and Israel, as it could allow Iran to proceed with assembly of its first nuclear warhead. Nevertheless, if Iran continues accumulating highly enriched uranium at the 60% level (even a large stock of it) but without building warheads, it can avoid a direct confrontation with the U.S. This scenario may also give opportunities to Iran to use deepening tensions between the West and Russia and/or China, while ruling out any further UN sanctions.

– *Breakout*—**Iran rapidly produces uranium for warhead cores despite IAEA monitoring**. This approach would be implemented at Iran's Natanz and Fordow enrichment plants, which are monitored by the IAEA. In this scenario, Iran could rapidly build not only the first nuclear test device but also a series of nuclear warheads in a few months. Moving from uranium enrichment of 60% to 90% (weapons-grade), Iran could also easily assemble the core of the first nuclear device. After its construction, the time necessary for the assembly of each subsequent warhead would be shortened to a few weeks (compare to earlier estimates in the main text). With larger quantities of LEU and advanced centrifuges, the time for this would be even shorter. However, this scenario also poses a high risk for the Iranian regime. Rejecting or preventing IAEA monitoring would trigger the agency's referral of issues to the UNSC. For the U.S and its allies, this scenario would imply the need for urgent decisions and even preventive strikes on Natanz and Fordow, while on the Iranian side it requires the need for the quick transfer of uranium cores to a secure site for warhead assembly. In moving forward under this scenario, Iran must be confident that it could assemble the first device quickly and integrate warheads into a well-tested means of delivery. Should such a work be detected, preventive strikes (even without the authority of the UNSC) could gain support from many European and Arab states. Therefore, success of this scenario requires Iran's full determination to build an arsenal and confidence in its security measures, as well as in the competence of the team responsible for integrating the warheads into the accepted means of delivery.

– *Sneak out*—**Iran secretly produces its first cores for nuclear weapons**. The country already partially succeeded in doing this until the revelation of its two, then-covert sites in the summer of 2002. Another element of this approach was the other Iranian covert facility at Fordow, detected and publicised by the U.S., UK, and France in autumn 2009. In this scenario, it is possible to simultaneously produce and stockpile of highly enriched uranium outside of IAEA monitoring while also avoiding UN interest in it. A prerequisite for the success of this option would be that the Iranian authorities maintain complete secrecy, at least until the beginning of the serial production of operational warheads. Iran would need then to perfectly conceal at least one additional uranium enrichment plant, as well as a centre for integrating warhead cores with their means of delivery. To date, the experience with Iran is that sooner or later even top secret projects or centres will be detected. The ineffectiveness of the security measures so far make it clear to the Iranian regime that this scenario is more risky than the two previously discussed. In this approach, Iran would also have to reckon with the determination of the U.S. and Israel to thwart its efforts, with even stronger international legitimacy for possible military actions. Iran's military credibility and feasibility of any *sneak out* would depend on the competence of its experts and technicians working on the assembly of uranium cores, the rate of production and number of warheads planned, and already tested means of reliable delivery. All in all, the success of this scenario would present the greatest number of problems and challenges for Iran, requiring preparations for very adverse international consequences.

It is worth stressing that, as of today, the scenario of Iran building an advanced thermonuclear arsenal can be considered only in the long term or with very extensive assistance from North Korea (possibly but much less likely from Russia or China).[51] Iran's scientific and technological progress in this direction may be residual at present, probably limited to some studies and the personal ambitions of its scientists. The construction of hydrogen weapons would be significantly facilitated if there was a further expansion of uranium enrichment plants or an HWR-class reactor and significant production of weapons-grade plutonium by them.

Nevertheless, Iran's development of a thermonuclear arsenal would be a logical step after the testing is completed and the gradual miniaturisation of its first-generation nuclear weapons. It would also show that the Iranian regime is interested not only in deterring Israel (with MRBMs) but also deterring and credibly threatening the continental U.S. (with ICBMs). Taking into account the evolution of other nuclear arsenals, the time required for Iran to build its first thermonuclear warhead would be a maximum of 5-10 years from the first test of a crude nuclear device. This timeframe might be significantly reduced in the case of deep cooperation between the physicists and warhead designers of Iran and North Korea (alternatively or also with Russia or China).[52] A very visible signal of Iran's progress in the direction of a thermonuclear arsenal could be more intense tests of SLV-class launchers or just overt tests of the first ICBM-class missiles.

Broader Determinants of Iran's Future Nuclear Decisions

Iran's strategy is likely to maintain—even for years or decades—the current approach to its nuclear programme and existing capabilities. This guarantees further development and the mastering of uranium enrichment capabilities and warhead studies, but without the risks that accompany building an operational arsenal and open confrontation with the U.S. and its allies. As noted, the *creep out* scenario offers the greatest freedom and flexibility for the Iranian regime to further collect a stock of highly enriched uranium, with a reduced timeframe for eventual testing and warhead assembly. With the continuation of this approach, Iran also gains time to develop and refine its own nuclear strategy and doctrine, determine the size of its arsenal and master further means of delivery.

This approach still appears to be favoured by the majority of the ruling elite and Khamenei himself. The Iranian government's frequent invocation of his religious opinion (*fatwa*) that nuclear weapons are incompatible with Islam does not determine the actual aims of the overall programme. Obviously, nuclear testing and building up an arsenal would be in stark contradiction to such rhetoric and international commitments, but such a contradiction might

[51] Hypothetically, some of the Iranian experts connected to the Amad Plan could continue their work on warheads on the territory of North Korea, i.e., probably beyond the reach of the U.S. and Israeli human intelligence. A further and related possibility would be for Iran to gain knowledge from North Korea on thermonuclear warheads, but without carrying out theoretical and practical work (weaponisation) on the territory of Iran.

[52] For example, North Korea's first thermonuclear test (160 kt yield) took place in September 2017, or 11 years after the Kim-1 nuclear test. However, the real record had already been set by the Chinese Chic-6 (3 MT yield) thermonuclear test only three years after the Chic-1 nuclear test. See Th.C. Reed, D.B. Stillman, *op. cit.*, pp. 125-129, and J.T. Richelson, *Spying on the Bomb. American Nuclear Intelligence from Nazi Germany to Iran and North Korea*, W.W. Norton & Co., New York 2007, pp. 189-192.

be limited.[53] With the continuation of its current attitude towards such a project, Iran would have a status similar to that of several other fissile material-producing countries without an actual arsenal ready for immediate use—the so-called *nuclear threshold states* such as Argentina, Australia, Brazil, Canada, Japan, South Africa, South Korea, and Taiwan, which have been recognised with this status for few decades.[54]

The circumstances of previous decisions by the Iranian regime on the overall nuclear programme and the shape of the Amad Plan also speak in favour of maintaining its threshold status. Iran under the monarchy was mainly driven by the prestige and long-term power ambitions of the Shah, and partly by Persian nationalism. Subsequent decisions by the authorities were probably also influenced by the Indian nuclear tests in 1974 and the Pakistan-India nuclear tests in 1998. However, the real national security threats were related to the post-revolutionary period and Iran's rivalries at that time with the U.S., Iraq, and Israel in the Middle East. The regime's pan-Islamic or messianic motives had little impact on Iranian strategic decisions after Khomeini's death. Iran, which had the experience of chemical warfare with Iraq, wanted to acquire a nuclear deterrent capability against Israel. Therefore, these decisions were rational from the point of view of the ruling elite, although always taken as a result of confidential consultations and unreadable to external observers. Each time, these decisions took into consideration the differing opinions in Khamenei's entourage, within the Iranian elite, and among the Revolutionary Guards. The initiation of nuclear talks in 2003 and 2012 was also indicative of the existence of a certain respect of the economic costs, sanctions, and isolation that the Iranian authorities may have feared to test.[55]

Iran's most far-reaching ambitions are primarily aimed at dismantling U.S. regional alliances and weakening Israel, but even with this strategy it may be more convenient to stay with a "virtual arsenal". Iran has used unconventional warfare and asymmetric means in its regional strategy for more than four decades. Initially, this was essentially terrorism accompanying "export of the revolution", and since 1989 the development of a missile arsenal with alliances beyond Syria and Hezbollah. Furthermore, Iran took risky steps vis-à-vis the U.S. by supporting local anti-American forces in Iraq and Afghanistan. But even in these cases, the IRGC's motives were linked less to Iran's official ideology and more to opportunism and the skilful exploitation of U.S. problems. Also, the building of the so-called Axis of Resistance was for the Iranian regime a defensive step against the U.S. and Israel, as well as an element of unconventional deterrence. At the same time, in all crises in which Iran has been met with

[53] According to the repeated Iranian statements in IAEA and AEOI documents, the *fatwa* (the opinion of a Muslim theologian) was said to have been issued in the mid-1990s and confirmed by another ones in 2005 and 2015, as declared in: *Iran's Statement at IAEA Emergency Meeting*, Vienna, 10 August 2015, https://fas.org.nuke/guide/iran/nuke/mehr090905.html. For a broader discussion of nuclear weapons and their perceptions by Shia and Sunni theologians and clerics, see: R. Mowatt-Larssen, *Islam and the Bomb: Religious Justification For and Against Nuclear Weapons*, Belfer Center for Science and International Affairs, Kennedy Government School, Cambridge MA 2011, and on Khamenei's general views of Iran's nuclear programme in: K. Sadjadpour, *Reading Khamenei: The World View of Iran's Most Powerful Leader*, Carnegie Endowment for International Peace, Washington DC 2008, pp. 22-24.

[54] In the British and U.S. terminology, these are "nuclear latency", "nuclear leveraging", "latent arsenal", and "virtual arsenal", and all are related to the concept of a "threshold state". For reflections on this and various definitions, see: A. Cohen, J.F. Pilat, "Assessing Virtual Nuclear Arsenals," *Survival*, vol. 40, no. 1, Spring 1998, pp. 129-144; M. Eisenstadt, *Iran's Hedging Strategy. Shaping the Islamic Republic's Proliferation Calculus*, Rowman & Littlefield, Lanham MD 2023, pp. vi-viii, 4-12; A.E. Levite, "Never Say Never Again. Nuclear Reversal Revisited," *International Security*, vol. 27, no. 3, Winter 2002/2003, pp. 59-88; and V. Narang, *Seeking the Bomb: Strategies of Nuclear Proliferation*, Princeton University Press, Princeton NJ 2022, pp. 15-52.

[55] In 2003, Iranian concerns about military regime change in Tehran by the Bush administration were key. In 2012, the very severe international sanctions packages and greater post-2010 determination on the part of some Israeli decision-makers to attack Iran's nuclear sites seem to be crucial factors.

determination and credible deterrence by its two main rivals, it has been quick to give up without risking further escalation and unwanted consequences.[56]

Iran's decisions to build warheads and to conduct nuclear tests may be also hampered by the experience of recent military crises with Israel. Indeed, Iran may reckon that a rapid military escalation with Israel would risk massive conventional retaliation with a powerful air force. Iran's first coordinated and hours-long air attack on Israel (13-14 April 2024), combining use of drones, cruise missiles, and ballistic missiles was almost entirely neutralised.[57] Despite the controversy over the Gaza operation, Israel received military support from the U.S. and other countries, including France and the UK, which also joined in its defence. The ballistic missiles used by Iran were mostly intercepted by Israel's multi-layered defences, proving the inaccuracy of the weapons targeting Israeli military bases. Moreover, Iran used most of its ballistic missile launchers in the attack, meaning that with the procedures required for reloading launchers it could not repeat another salvo on Israel in less than a few hours. The situation was repeated during Iran's second attack (1 October 2024), although the change in tactics and the use of solid-fuel ballistic missiles this time likely strained Israel's defences. All these factors taken together may direct the Iranian rulers and the IRGC's commanders to review the technologies, structure, and size of future missile and nuclear arsenals with the assumption that salvos of even 80-100 nuclear warheads would be intercepted by Israel and the U.S.[58] Iran's decision to hastily integrate future nuclear warheads with longer-range missiles may be also complicated by the operational readiness of defence systems for the continental U.S. (GMD) and the European NATO area (EPAA).

Nevertheless, the circumstances favouring Iran's current posture may change with a different perception of the Israeli threat or the death of Khamenei. Indeed, both Iran-Israel military crises in 2024 could be equally perceived a failure of the earlier strategy towards Israel based on pro-Iran forces in the region. As early as in the spring of 2024, there were several statements by Iranian politicians and IRGC officers suggesting some sort of revaluation of their thinking about nuclear issues, justified by Israel's clearly visible military edge and superiority.[59] It should be noted that most of these signals came from members of parliament (the Majlis), which does not have a decisive role in issues of Iran's national security and nuclear programme. However, comments on the topic by close advisors to Khamenei and high-ranking members of the IRGC should not be dismissed, as well as the fact that in the past the Majlis has been used to test the reactions of the P5+1 negotiators, IAEA inspectors, and Western experts.[60]

---

[56] See, in particular, D.B. Crist, "Gulf of Conflict. A History of U.S.-Iranian Confrontation at Sea," *WINEP Policy Focus*, No. 96, June 2009, and M. Eisenstadt, "Deterring Iran in the Gray Zone: Insights from Four Decades of Conflict," *WINEP Policy Notes*, No. 103, April 2021.

[57] On the course of and defence against Iran's first strike, see: U. Rubin, "Operation 'True Promise': Iran's Missile Attack on Israel," *Begin-Sadat Center Perspectives Paper*, No. 2281, 18 June 2024. For a preliminary impression of the second strike, see: M.A. Piotrowski, "A new level of escalation between Iran and Israel," *PISM Spotlight*, No. 63, 3 October 2024. In the first case, the efficiency of the Israeli interceptions reached 95%, while in the second up to 75-80%.

[58] Iran may have possessed about 300-400 MRBMs with a range of 2,000 km, but according to various non-governmental estimates, it has a small number of launchers for them, and in the author's opinion about 25-50 (there are no unclassified U.S. or Israeli intelligence estimates on these). Compare with propulsion issues in the next section on options of delivery.

[59] Cf.: E. Gernmayeh, "Iran Has Every Reason Now to Go Nuclear," *Foreign Policy*, 24 October 2024, https://foreignpolicy.com, and AFP, "Israeli retaliation threat sparks call in Iran for nuclear weapons," *Al-Monitor*, 10 October 2024, www.al-monitor.com.

[60] A comment by the Supreme Leader's advisor Kamal Kharrazi in October 2024 may be considered the most serious voice on the matter. On his opinions, see: A. Almendrai, A. Khodadi, A. Jones, "Iran says it has the capacity to make nuclear weapons: supreme leader threatens U.S. and Israel," *NBC News*, 1 November 2024, www.nbcnews.com, and P. Hafezi, "Iran adviser hints at expansion of missile range, nuclear doctrine review after Israel strikes," *Reuters*, 1 November 2024.

Therefore, Israel's success in degrading Hezbollah's military strength, the unexpected collapse of the Assad regime in Syria, and the uncertainty about future U.S. policy may prompt both Khamenei and his advisers to rush with building a nuclear arsenal. The events of 2024 are questioning the previous rules and practice of conventional deterrence between Iran and Israel. In the past, one of the main motives of the Amad Plan seems to be Israel's nuclear monopoly in the Middle East, and the threat from it is likely to grow proportionally to Iran's waning influence. Moreover, the Ukraine case (violation of the so-called Budapest Memorandum) and the exit of the first Trump administration from the JCPOA may be pros for a faster *breakout* or *sneak out* scenario, using the uranium stocks already accumulated in various forms. Similar to the period before 2015, decision-makers in Tehran may also have concluded that the denuclearisation of Ukraine, Iraq, and Libya have not protected them from Russian aggression or regime change by the U.S., while a nuclear North Korea still enjoys relative security at the price of isolation and sanctions.

Another important factor for potential changes in the Iranian assessment of the Israeli or U.S. threat may be the domestic situation. In virtually every scenario, Khamenei's successors will sooner or later face the decision to keep the existing, mostly virtual nuclear programme or to build an operational arsenal. At present, Khamenei still enjoys good health for a politician at the age of 85.[61] However, on his death, Iran's next Supreme Leader must ensure the stability and survival of the regime. The succession process itself is already complicated by the death in the helicopter crash of President Raisi, who was perceived by observers to be the favourite and an almost certain successor to Khamenei. The remaining possible contenders to succeed the current Iranian leader may be more controversial to various informal groups and factions within the Shia clergy.[62] The violent protests of 2022-2023 showed that for the IRGC, it is difficult to control and quick to pacify younger generations and ethnic minorities. That means that Iranian society is unlikely to be passive after Khamenei's death. The ruling clergy, Revolutionary Guards, and other beneficiaries of the regime are likely to try to make the succession process as smooth as possible, but it may end in perturbations or even full collapse. Looking into the future, it is also not out of the question that some role will be played by the Iranian diaspora, which in recent years has undergone deeper generational changes.[63]

Iran's eventual decision to build a nuclear arsenal may also come from the greater political influence of the Revolutionary Guards, which are willing to continue their confrontation with Israel and the U.S. Previously, the IRGC supported and was a custodian of the Amad Plan, but it never challenged any of Khamenei's essential strategic decisions on nuclear issues. However, the Corps' approach could change, and a new leader might be even more friendly to the IRGC or even fully dependent on it. Thus, Iran's nuclear arsenal could become an attractive umbrella for riskier and more aggressive moves in the Middle East than those behind past crises caused by Iran in the Persian Gulf or Red Sea.

[61] According to World Bank estimates, the life expectancy of men in Iran has reached 73 years. Recurring rumours of advanced prostate cancer, complications from COVID-19, and opium abuse by Khamenei have so far not been confirmed.

[62] For a summary of the main challenges regarding the succession of Khamenei, see: A. Ostrovar, "The Looming Battle for Succession in Iran," *Engelsberg Ideas*, 16 May 2024, https://engelsbergideas.com.

[63] Most of the Iranian diaspora maintains family ties in Iran. For several decades, it was rather passive and divided between the fiercely conflicted monarchists and the radical leftist People's Mujahedin. Since the Iranian protests in the autumn of 2022, the activation of leaders of a new generation of émigrés has been observed, both resentful of the regime and these two historical forces.

The Likely Means of Nuclear Weapons Delivery Available to Iran

In case Iran develops nuclear warheads, it will have to integrate them with one or more types of delivery. Iran's decision in this area will be derived from its priority military targets and proven weapons systems. The Iranian regime declares that it is satisfied with possessing ballistic missiles with a range of up to 2,000 km to strike targets in the Middle East. Iranian diplomats during their talks with the West cite Khamenei's statement on the topic and declare a lack of interest in missiles with longer ranges. A comparison of estimates of their missile technical parameters suggests a *de facto* focus by Iranian missile developers on systems reaching around 2,000 km (see Appendix 4 for more details). As with the nuclear programme, Iran's declared self-restraint can hardly be seen as fully clarifying its actual intentions and capabilities. In recent years during attempts to revive the JCPOA and discussions of possible annexes to the agreement, Iran has described any formal limits on its missiles as "non-negotiable". At the same time, Iran has shown a willingness to deliver ballistic and cruise missiles or kamikaze drones it produces to any of its *Axis of Resistance* allies, and since summer 2022 provides them to Russia too.

Some of Iran's already available or technically feasible options seems to be unrealistic and unpractical, and that is the case with radiological weapons. In theory, Iran could also use a crude nuclear device against Israel, a system without special design, miniaturisation or shielding as necessary in a ballistic missile or aerial bomb. According to some estimates, it would take Iranian scientists and technicians 6-12 months to assemble a simple uranium-core device.[64] Building a radiological bomb would be even less technically demanding, thanks to isotopes that are easier and cheaper to produce than enriched uranium or plutonium. Iran could use the help of Lebanese Hezbollah for a "dirty bomb" attack on Israel. The detonation of several such improvised radiological or nuclear devices by truck or civilian ship could cause shock and panic in Israel, at least for a short period, but scenarios for such an attack seem unlikely. Iran—by choosing such means of what would surely be deemed a terrorist attack—would risk Israel intercepting the carrier and device. If it were successful in staging a radiological or nuclear improvised weapons attack, Israel's military retaliation would likely involve some nuclear retaliation with high casualties among Iranian civilians.[65]

An Iranian surprise attack with a first nuclear strike could be exploited by the further development of its torpedo drones.[66] In the future, Iran could even integrate its first-generation nuclear devices with a larger maritime drone. This would give Iran a chance to deal great damage in an attack on an Israeli port, such as Eilat, or on the main U.S. naval base in the Persian Gulf, Manama. In a regional war, Iran could also hypothetically mount some of its nuclear warheads on customised gravity bombs for its air force. However, the capabilities of Iran's aircraft fleet have seriously degraded over four decades, relying still and mainly on obsolete U.S. aircraft. Iranian decision-makers' confidence in nuclear dumb bombs will not be boosted even with the delivery of more advanced Russian Su-35 tactical bombers. Essentially,

[64] Such options for Iranian nuclear devices and strikes were analysed in the full version of the previously quoted NIE and in the text of a separate NIE on Iran's armed forces. See: V.H. Van Diepen, *op. cit.*, p. 186. The coordinator and editor of this second "military NIE" was Steven R. Ward, a CIA analyst.

[65] Even if Hezbollah or another militia were to admit to a successful attack on Israel, the main suspects in the delivery of a radiological or improvised nuclear device would be the Iranian IRGC. Israel in retaliation for a "dirty bomb" could strike, for example, Iran's reactors, and in the case of an attack with an improvised nuclear device, even carry out massive nuclear retaliation.

[66] At present, Iran's experience with the Nazir-5 maritime drone could be the start of such a design. See: H.I. Sutton, "New IRGC Uncrewed Underwater Vehicle: Nazir-5," *Covert Shores* (blog), 24 November 2003, www.hisutton.com. For more about North Korea's revealed Haeil drone-torpedo design, see: B. Lendon, Y. Seo, "North Korea claims to have tested a nuclear capable underwater drone. Analysts are skeptical," *CNN*, 24 March 2023.

even rapid modernisation of Iran's military aviation will not solve its main issues, including the low level of training and lack of experience of pilots and the high probability of their nuclear mission being intercepted by Israeli or U.S. defences.[67]

The Amad Plan files show advanced studies on the integration of a nuclear warhead with the Shahab-3 ballistic missile. Among experts there are discrepancies as to the estimated range of this missile in different versions, from 1,000-1,300 km to as much as 1,300-1,500 km with a warhead of up to one tonne. But as mentioned earlier, the orchestrated research within the Amad Plan of Project 110 and Project 111 on a re-entry vehicle for a nuclear warhead was likely discontinued in 2003. It is difficult to estimate how much time Iran would need to operationalise this, that is, to put into service a system that has already been fully proven in a series of tests. Available documents confirm preliminary calculations and computer simulations, as well as proven solutions and sketches for the integration of the two elements, but there is no evidence of the development or test of a full-scale mock-up of a nuclear warhead within Project 111. Obviously, their assembly and use in tests of the post-2003 Shahab-3A and post-2004 Shahab-3M versions cannot be completely ruled out. Both models of the Shahab-3 with conventional warheads became one of the pillars of the current IRGC Air and Space Force's arsenal. The newest versions of these missiles (Gadr-1 and Emad) already have a 750 kg warhead payload and a range of 1,700-2,000 km, a significant advance over the basic Shahab-3A.

During the previous decade, the prevailing assessment was that the entire process, starting with assembly and testing of the first nuclear device to its later integration with the Shahab missile would require 2-3 years. Now, with any possible resumption of Iran's Project 111 and its cumulated experience, the time for the warhead's aerodynamic testing would be reduced, perhaps to even 12-24 months. Testing the Shahab-3 with a mock-up of a nuclear warhead would be now less demanding and shorter, if necessary at all. In a worst-case scenario, it is even possible that a re-entry vehicle with shielding and a full-scale mock-up of a warhead has been tested with other Iranian ballistic missile models.[68] Two decades after the original Amad Plan, however, an important military issue for Iran may be whether the nuclear-armed Shahab-3 still meets its strategic expectations, especially in the case of Israel. This missile is a liquid-fuelled design, and due to the corrosive properties of this fuel, the Shahab cannot be kept on combat alert frequently or for long periods of time. Preparing the launchers and filling Shahab-3 missiles with kerosene fuel is a time-consuming procedure taking several hours at best. It is now possible to track even its mobile launcher and detect the launch with satellite or drone reconnaissance, and the time to load the next missile exposes it to destruction by the enemy.[69] In sum, all these factors indicate that even simple projections of Iran's future capabilities should assume alternative options to Shahab-3 missiles.

The warhead model studied during the Amad Plan cannot be simply integrated with Iran's other existing missile designs. Due to warhead payload mass limitations, ballistic missiles of the Fateh-Zulfiqar family (range of 250-700 km) can be ruled out. Although the designs of successive versions of the Fateh were successful—it is solid-fuel propelled and

[67] Problems with the supply of spare parts for the U.S.-made F-4 and F-5 aircraft and the training of Iranian pilots were likely important motives for seeking Scud missiles from Libya and North Korea in 1985-1988. See: S.R. Ward, *Immortal. A Military History of Iran and Its Armed Forces*, Georgetown University Press, Washington DC 2009, pp. 271-273, 291-292, 316-318.

[68] The main challenges during flight testing of missile designs are related to their ability to withstand vibration during the lift and ascent phases and the extreme temperatures of the re-entry vehicle in the atmosphere and the terminal phase of the warhead as it descends to its target.

[69] The Shahab-3 is a copy of the No Dong-1 missile, which is an enlarged modification of the Soviet R-17 SRBM. For a more extensive discussion about the evolution of North Korea's R-17 derivative missiles, see: J.S. Bermudez Jr., "A History of Ballistic Missile Development in the DPRK," *CNS Occasional Papers*, No. 2, Monterey CA 1999.

combat-proven—it cannot carry a warhead of the parameters foreseen for the Shahab-3. The Fateh family missiles as a nuclear warhead delivery mean would require significant and further miniaturisation of the payload and a series of separate nuclear tests. While a version of the Fateh with a nuclear warhead cannot be ruled out in the future, it is more feasible to continue using it for conventional deterrence, because of its proximity to U.S. bases (Iraq, Kuwait, UAE) and the greater number of launchers available to Iran.[70] Equally unrealistic is the integration of the Amad Plan warhead in any of Iran's existing cruise missiles. While most of these have a longer range, this is achieved with smaller mass and size of their conventional warheads. Iran's cruise missiles (Abu Mahdi, Howaizeh, and Soumar types) with a range of 1,300-2,000 km carry conventional warheads up to 200 kg, which means they would require a nuclear warhead half the weight and size of the one known from the Amad Plan.[71] Therefore, as with SRBM-class missiles, Iran's new cruise missiles and heavy kamikaze drones will not be alternatives to proven MRBM-class missiles any time soon.

The Khorramshahr ballistic missile could be the other option to deliver Iran's nuclear weapons to strike targets in the region and Europe. Indeed, this missile has a declared range of 2,000 km and carries a conventional cluster warhead weighing as much as 1.8 tonnes—the same model could also deliver a large amount of chemical weapons. However, tests in 2017-2018 with cluster munitions are believed to have not taken place at maximum range. The Khorramshahr is an Iranian modification of the Musudan (Hwasong-10) missile, and 18-19 of these were previously delivered by North Korea.[72] In the past, and due to the changing international climate, the Musudan family missiles have not been tested by Iran for more than a decade since their transfer in 2005. Some of these may also have been used in some of the Iranian Space Agency's SLV launches. North Korea tested the Musudans with 650-750 kg warhead payloads at a range of up to 2,500 km (MRBM-class), and some with a 500 kg warhead at 3,000-4,000 km range (making them IRBM). The remaining 10-15 Musudans in Iran's possession, if armed with a nuclear warhead, would pose a potential threat to Europe. As the Musudan-Khorramshahr case shows, Iran can also modify its missiles with or without further cooperation from North Korea. The latest version of these (Khorramshahr-4) was demonstrated in May 2023 and was said to be capable of carrying a 1.5-tonne warhead for 2,000 km.[73] It should also be stressed that Musudan engines and experience were used by North Korea in the development of its first intercontinental missiles with warheads weighing up to 500 kg (of the Hwasong-13 and Hwasong-14 type).

The integration of Project 110's warhead also would be a feasible option in the case of some improvements of the Sejjil-2 ballistic missile, so far Iran's most secretive design. This two-stage solid-fuel missile with a 650-700 kg warhead and a range of 2,000 km was tested

[70] It is possible that Iran will gradually replace its SRBM-class arsenal over the next 5-10 years, with more Fateh-family missiles and launchers instead of liquid-fuel Scud-type missiles (Shahab-1/2).

[71] Iran acquired several Soviet Kh-55 missiles in Ukraine in 2001, capable of carrying a 400-450 kg warhead over a range of 2,500 km. The dimensions of the Project 110/Amad Plan warhead would be too large for mounting on tested Iranian copies or modifications of the Kh-55. See: M. Elleman, *Open Source Analysis of Iran's Missile and UAV Capabilities and Proliferation*, IISS, London April 2021, pp.18 and 24-25.

[72] The question of the very existence of the Musudan missile was disputed during confidential U.S.-Russian talks until their demonstration at a parade in Pyongyang in 2010. Russia's denials stemmed from North Korea using the Soviet R-27 missile documentation purchased illegally in Russia. Moreover, the threat of Iran's Musudans justified the plans for the NATO-EPAA missile defence system in Romania and Poland. See more in a copy of retransmitted cables from the U.S.-Russian discussions on this topic, published by WikiLeaks: "U.S-Russia Joint Threat Assessment Talks - December 2009, Secretary of State to US Embassy Moscow," Wikileaks, Washington DC 24 February 2010, http://cablegate.wikileaks.org/cable/2010/02/10STATE17263.html.

[73] Cf. J. Bennie, "Iran unveils Khorramshahr-4 ballistic missile," *Jane's Defence Weekly*, 25 May 2023; R. Einhorn, V.H. Van Diepen, *op. cit*., pp. 11-12; and M. Elleman (ed.), "Iran's Ballistic Missile Capabilities. A Net Assessment," *An IISS Strategic Dossier*, May 2010, pp. 32-34.

several times in 2008-2011 and in a single test in 2021. The Sejjil-2 with a modified Amad Plan warhead would pose a more complex threat to Israel than the previously discussed missiles. The technological leap to solid-fuel propulsion and the capability for permanent combat duty was a surprise to experts in 2008. The missile's design, when refined and with an additional stage (speculative Sejjil-3 model), could theoretically strike targets as far away as 3,000-4,000 km, making it then IRBM-class.[74] Apart from political reasons during the JCPOA negotiating period, however, there is a lack of convincing explanations for the stagnation in the development of the Sejjil-family missiles. The Iranian government claims that its basic version has been in service since 2014. If that is true, Iran may have at most 5-15 missiles and/or launchers for these. One plausible explanation for the suspension of further testing of the Sejjil-2 seems to be that its design is underdeveloped and solid fuel composition still too risky for serial production and mass service. This could be the reason for the explosion of one of its prototypes in November 2011, which killed its designers and "the IRGC's architect of the missile programme" himself, Gen. Hassan Tehrani Mogghadam.[75]

Assessing the long-term developments of Iran's arsenal, it may be assumed that it would also opt for intercontinental ballistic missiles, perhaps exclusively as the delivery mean of thermonuclear weapons. Iran's "civilian" rocket programme (SLV-class) as observed so far still relies on liquid-fuel technology from North Korea. Iran also experienced delays in its SLV programme, which might have slowed the prospects for their rapid conversion to ICBM-class. Due to the long-standing cooperation with North Korea, further transfers of the DPRK's missile technologies to Iran may be likely within a few years. It should also be stressed that North Korea's models of this missile class may already be carrying thermonuclear warheads, optimal for continental U.S. strikes and deterrence. Moreover, it is doctrinally and technologically possible that Iran will follow the path of the nuclear and missile arsenals of the USSR, North Korea, and China, beginning with medium- to intercontinental-range missiles, from liquid- to solid-fuel propulsion, and from large nuclear warheads to miniaturised nuclear or thermonuclear warheads.[76]

Basic U.S. Strategic Response Options

Most of the strategic approaches used so far by the U.S., the EU, and Israel towards Iran in the best of circumstances have shown limited or short-lived effectiveness. Solutions hiding under the very general slogans of a "grand bargain" or "regime change" remain too radical and risky to be on the Trump administration's agenda as early as the beginning of 2025. Also, neither the U.S. nor the Iranian government is likely to make far-reaching and unilateral concessions, so these options now seem completely unrealistic.

Since the disclosure of Iran's military programme in the summer of 2002, various U.S. options and strategies for response have been discussed and debated.[77] As pointed out, some of them already seem to be outdated or unrealistic. Predicting the policies of the new U.S. administration

[74] M. Elleman, *ibidem*, pp. 54-64, 110-112.

[75] Media at the time suggested another case of Israeli sabotage in Iran. An explosion of an unstable solid fuel mixture seems more plausible and accurate to the author, which would be analogical to the *Nedelin disaster* or *Baykonur catastrophe* with the R-16 ICBM prototype at Baikonur in October 1960 in which there were 100 victims, including the head of the Soviet Strategic Missile Forces, Gen. Mitrofan I. Nedelin.

[76] Iran's analogies to the thermonuclear arsenals of the U.S., UK, and France are not justified, mainly due to the sophistication and roles of strategic aviation and submarines in these three powers' nuclear triad or dyad.

[77] Compare options analysed, in particular, in: Z. Brzezinski, S. Maloney, R.M. Gates (eds.), *Iran: Time for a New Approach. Report of an Independent Task Force*, Council on Foreign Relations, New York, July 2004; C.H. Kahl et al, *If All Else Fails: The Challenges of Containing a Nuclear-Armed Iran*, Center for a New American Security, Washington DC, May 2013; Th. MacDonald, P. Roemer, E. Klein, "Our Remaining Options for Preventing a

is difficult given the personality of Trump and his frequently contradictory statements on Iranian issues during just the 2024 election campaign.[78] It is possible that his approach will be a result of his personal dislike of Iran, lack of understanding of the U.S. constraints and merits of the JCPOA, and close relationship with the current prime minister of Israel, as well as the transactional approach to other regional allies. It is also difficult to determine the real impact on the new administration of Vice President J.D. Vance, who is reluctant towards a U.S. military presence in the Middle East and appears to have more distance to Israel. Nevertheless, the Republican majority in both chambers of the U.S. Congress gives Trump a strong political base and the possibility of easy approval from his new senior officials. Notwithstanding all these important factors and the coherence of the new president's cabinet, mid- and lower-level U.S. officials may try to present him with range of rational options. The new US administration may n the beginning of 2025 therefore still be weighing the pros and cons of the following strategic options:

– **U.S. nuclear compromise with Iran**. The aims of this approach are limited to the nuclear issue and—as with the JCPOA—include transparency, full inspection, and limiting Iran's capabilities to quickly build a nuclear arsenal. This approach is likely to get broad support from all EU countries and most U.S. allies, even in some interim form. An example of this would be to "freeze the work" of Iran to a level of 19% or 20% enriched uranium. Such a step by Iran would be a goodwill gesture and increase the chances of a return to the original JCPOA limits or even the start of negotiations on a new and comprehensive agreement—*JCPOA-II*. However, as the Obama administration's issues with the JCPOA showed, this option might be unsatisfactory for Israel and Saudi Arabia, as well as for the U.S. Congress (opposition also came from some Democrats). This approach of focusing on reaching for some *JCPOA-II* deal does not guarantee the desired, positive change in the regional situation or full control over the possible next Iran-Israel crises. Moreover, expectations of a smooth move from the nuclear deal to a much broader compromise (the so-called U.S.-Iran "grand bargain") were unrealistic even at the time of its signing in 2015. This approach also does not give the West the opportunities to have some influence on the internal situation and promote positive changes within Iran. The Iranian regime can also negotiate a new deal with the U.S. for many years, but at the cost of further Western concessions on economic, regional, and domestic issues.

– **U.S. active containment of Iran**. The essence of this approach is either to slow down Iran's nuclear programme (minimum U.S. goal) or to change all other negative aspects of its policy (maximum U.S. goals). The experiences of the Clinton, Bush, and the first Trump administrations showed that the implementation of this option is difficult without the equally active involvement of European and Arab countries. In the case of the first Trump administration, this was the policy of "maximum pressure" on Iran, announced with the U.S. exit from the JCPOA, elements of which were the 12 (then 13) demands and the termination of the agreement in May 2018, as well as the failed initiative of the so-called Warsaw Process

Nuclear Iran," *MIT Science Policy Review*, vol. 1, December 2020, pp. 92-98; and K.M. Pollack, *The Persian Puzzle. The Conflict Between Iran and America*, Random House, New York 2004, pp. 375-424.

78 During the 2024 campaign, U.S. intelligence revealed that the Iranian regime was to be considering—and even preparing—plans to assassinate Trump and a group of officials of his first administration. In addition, Iran was engaged in active disinformation and cyberattacks aimed at Trump losing the election. He himself suggested on one occasion that he would support Israeli strikes on Iran's nuclear facilities and on another, asserting that he was fully prepared to lift U.S. sanctions and negotiate a new nuclear deal with Iran. See: AFP, "Trump says he thinks Israel should 'hit' Iran nuclear facilities," *The Times of Israel*, 5 October 2024, www.timesofisrael.com; K. Frazier, "Trump makes a surprising overture to Iran at NYC press conference," *Politico*, 27 September 2024; and J. Sakellariadis, "Iran has a hit list of former Trump aides. The U.S. is scrambling to protect them," *Politico*, 11 October 2024, www.politico.com.

(named after the Warsaw Conference in 2019).[79] However, Iran's approach to the previous three U.S. administrations was quite effective in torpedoing the Middle East peace process (via support for Hamas and Hezbollah) and in parallel proxy strikes or harassing U.S. forces in Syria and Iraq. Therefore, with this approach the Trump administration has to reckon with some likelihood of escalation of regional tensions and terrorist threats by Iran, and above all, the greater risk of its decision to build a nuclear arsenal. Renewed sabotage of Iran's nuclear programme may also be an element or variant of this approach, but the U.S. will not take actions as risky and bold as Israel (for example, the elimination of Fakrizadeh and his successors).[80] It cannot be excluded that the rapid collapse of the pro-Iranian regime in Syria might encourage the Trump administration to escalate with such multi-dimensional pressure on Iran.

– **Preventive strikes by Israel**. In this option, the initiative belongs to Israel but the possible consequences of its strikes would require bilateral arrangements with the U.S., which was opposed successively by the Bush, Obama, Biden, and some advisers in the first Trump administration. Israel so far does not have high confidence that Trump's second administration will fully accept or tolerate such a risky option. For years, repeated U.S. opposition to this solution has been also the topic of behind-the-scenes disputes within Israel itself.[81] It is also likely that the details of the Israeli-American consultations would be leaked to the media, thereby sabotaging the element of surprise and operational security of Israeli action. Moreover, for at least a decade, a significant gap has persisted between the cautious intelligence estimates of Iran's nuclear intentions and their perception by successive Israeli governments.[82] For the U.S., the main issue with Israeli preventative strikes are the expected consequences, including the rapid escalation of the conflict to a regional scale, some kind of retaliation against Israel by Lebanese Hezbollah, and retaliation by pro-Iranian terrorists on Americans. It should also be noted the limitations of Israel's conventional military capabilities (aircraft, drones, and cruise missiles) that prevent it from the destruction of all of Iran's known nuclear sites. At best, an Israeli strike or strikes would only postpone the emergence of an Iranian nuclear arsenal by several years. Moreover, it must be stressed too that Israel's earlier preventive strikes on reactors in Iraq and Syria are no longer as relevant given Iran's more advanced and dispersed nuclear-industrial base.[83] And therefore, overall, Israel has a growing credibility problem with its "red lines" or "critical points", announced for more than 20 years now against Iran by its governments, while the most recent Israeli declarations are concerns and warnings of Iran's uranium enrichment above the 60% HEU level.

– **The U.S. military campaign**. Contrary to media speculation in the past, this approach has never been of interest to successive U.S. administrations. However, periodic updates to

[79] See the original 2018 demands on Iran in: M. Pompeo, "After the Deal: A New Iran Strategy," The Heritage Foundation, Washington DC, 21 May 2018, www.heritage.org.

[80] Contrary to prevailing opinions at the time, Iran did not retaliate with attacks by Hezbollah or on Israeli embassies after Fakrizadeh's elimination in November 2020. See: M.A. Piotrowski, "Assassination of the head of the military aspects of Iran's nuclear programme," *PISM Spotlight*, No. 88, 1 December 2020.

[81] Media leaks at the time and subsequent memoirs by Defence Minister Ehud Barak show that the most serious discussions on the topic took place between 2010 and 2012. See: "Israel called off 2012 strike on Iran because it coincided with joint US drill," *The Times of Israel*, 21 August 2015, and R. Bergman, M. Mazzetti, "The Secret History of the Push to Strike Iran," *The New York Times Magazine*, 4 September 2019.

[82] The author noted these differences in conversations with Israeli officials and experts in 2012, 2013, and 2015, and they may have been exacerbated after the JCPOA deal. See also: E. Fabian, "Military Intelligence Backs Revived Iran Deal, Breaking With IDF Chief, Mossad," *The Times of Israel*, 26 June 2022.

[83] The Fordow plant set within rock tunnels was evidently built with the idea of full protection from Israeli or U.S. conventional airstrikes.

Pentagon plans and even the presentation of such an option to Trump cannot be ruled out.[84] The U.S. intelligence and reconnaissance as well as the air force and navy, offer the hypothetical capabilities to destroy all of Iran's nuclear infrastructure. But this option would require the U.S. to carry out a high-intensity campaign (days to weeks) of air and missile strikes on Iran, and dropping special bunker-busting conventional bombs (to penetrate rock and concrete), and also striking multiple targets associated with the IRGC.[85] During the course of such a U.S. operation, there could be an Iranian blockade of Persian Gulf oil tanker traffic with subsequent destabilisation of the global oil market. In the context of a military escalation, the U.S. could be forced to rapidly expand its list of targets in Iran or face another difficult decision to attempt regime change in Tehran. However, it is doubtful that the U.S. military after their experience of intervening in Afghanistan and Iraq or the civil wars in Libya and Syria would recommend the *regime change* option to Trump. It is likely that any decision on it would have been sabotaged within the Pentagon itself and actions towards it revealed to media, especially if the U.S. plans were also to include some ground forces operations in Iran. Regardless of the risk of terrorist retaliation against Americans and Iranian missile attacks on Israel in retaliation, this option does not ensure that Iran after the U.S. strikes would stop building a nuclear arsenal in better-concealed and protected facilities. Even in the context of some expected improvement in U.S.-Russia relations under Trump, Russian and Chinese support in the UN Security Council for legitimising a U.S. military campaign is extremely unlikely.

– **Nuclear deterrence of Iran**. This tool is already present in the options for compromise and containment, but has not been explicitly and frequently articulated by U.S. administrations to date. The premise of this approach does not rule out any of Iran's possible arsenal scenarios (*breakout* and *sneak out*), and may be complementary to even a formal U.S. deal with Iran as a nuclear threshold state. This option assumes an effective and credible American nuclear deterrent vis-à-vis Iran, including extended security guarantees for Israel and perhaps even Arab regional allies. However, it requires very clear communication to the regime in Tehran that any nuclear attack by it will end in inevitable and massive retaliation by U.S. nuclear forces.[86] The problems with this approach are Iran's opportunism in the region and the management of escalation control in the case its unconventional and conventional attacks, especially when in future combined with its nuclear blackmail.[87] This strategic approach or option might be questioned by some influential experts in the U.S. and Israel, who perceive contemporary Iran as an irrational and unpredictable state actor.

Implications for the EU and Poland

Europe has so far had limited influence on the U.S. strategy and instruments regarding Iran. In fact, Europe has had to align itself each time and sometimes reluctantly with U.S. interests

[84] In the Bush Jr. administration, Vice President Dick Cheney was said to be in favour of this option. Still, the argument for it implementation might be the significant limits on Israel's side and the expected greater military effectiveness of U.S. air and missile strikes.

[85] The Pentagon had been receiving special 8.5 tonne GBU-43B MOAB conventional bombs from the U.S. defence industry since 2003, which are capable of penetrating underground sites in Iran and North Korea.

[86] According to media reports, the Biden administration, beyond its public warnings, delivered a letter to the Iranian regime in April 2024 reiterating security guarantees to Israel but with the caveat of its lack of interest in a U.S.-Iran escalation. See: A. Shalal, "Biden says he expects Iran to attack Israel soon, warns: 'Don't'," *Reuters*, 13 April 2024, www.reuters.com.

[87] The topic goes beyond the issues of Iran's nuclear arsenal and strategy, requiring, for instance, an analysis of the few military crises between Pakistan and India since 1998. From Poland's point of view, some analogies with a nuclear Iran may be reflected in Russia's behaviour and nuclear threats during the war with Ukraine, and these hampered important decisions by Biden.

and policies. Also, as with the first Trump administration, completely independent initiatives by the EU3 or the EU as a whole vis-à-vis Iran run the risk of failure in the absence of his interest and close U.S.-European coordination. However, issues of Iran's nuclear programme may turn out to be just one of many affecting overall transatlantic relations. The peculiarities of Trump's persona also do not make it possible to predict whether the U.S. containment of Iran will be favoured throughout his presidency or will become just a prelude to other options. Trump may be willing to ignore the interests of Europeans, while the latter may have serious problems agreeing on a unified EU position on Iran.

The EU's approach (or even lack thereof) to Iran's nuclear programme is likely to be heavily influenced by reactions to Trump's preferred strategic options, or possibly by Israel's opportunism. The majority of EU states remain committed to the principles of the NPT and the prevention of nuclear weapons proliferation globally and in the Middle East, and therefore will support the option of a nuclear compromise with Iran. Some EU countries will also take into account the regional and internal situations of Iran when formulating their positions. The EU's policy on Iran will also have to consider the tightening Iran-Russia alliance and Iranian assistance to Russia in its continued war against Ukraine. Furthermore, even with a good climate in talks about U.S.-EU coordination, it may happen that substantive arrangements with State Department officials later do not have the understanding and support of the White House. Also in this context, for Europe it will be important to maintain the exchange of up-to-date information and intelligence estimates on Iran, or at the least to monitor any potential rifts between the U.S. intelligence community and policies and high-ranking officials of President Trump.[88]

It can be assumed that Poland's presidency of the EU in the first half of 2025 will coincide with the Trump administration's clarification of its global and Middle East policies. During this time, Poland will also have to have formulate its own approach to the progress of Iran's nuclear programme, the chances of concluding a *JCPOA-II*, or the prospects of a U.S.-Iran confrontation. It also likely will be a time of more intensive Poland-U.S. consultations on Iran.[89] Their interests converge on avoiding a scenario in which Iran builds a nuclear arsenal. But in the short term, Poland's policy towards Iran in NATO, the EU, and the UN should still be put with the context of Iran's alliance with Russia, as military cooperation between Russia and Iran is not a temporary problem. Therefore, Poland should support further tightening of EU economic and technological sanctions, which in an optimal scenario should be synchronised with similar U.S. sanctions. Poland should also signal to the Iranian government at every opportunity that their alliance with Russia impinges on current and future bilateral political, economic, and cultural relations, even though at a low level already.

Conclusions

Iran has achieved most of its ambitious goals 50 years after the launch of its civilian nuclear programme and equally 22 years after the disclosure of its covert military programme. For

[88] During Trump's first presidency, there was almost open conflict between him and the U.S. intelligence community. From the beginning of his second presidency, it can be expected that he will try to enact a policy towards Iran independent of professional intelligence and assessments. Depending on the staffing of the heads of national intelligence and the CIA, there may also be issues of so-called intelligence politisation of estimates by Trump's advisers and political officials.

[89] From the point of view of Poland and NATO, it is worth noting an additional aspect, which is the already operational base of the EPAA system and Aegis Ashore site in Redzikowo, Poland. There is the possibility that some of Trump's advisors will promote the idea of returning to the idea of a fourth phase of the EPAA (SM-3 Blk. IIB interceptors), through which the system would also serve to defend U.S. territory against Iranian ICBMs. Nevertheless, at the moment of writing, the opposite scenario of cancelling U.S. interests in the missile defence of Europe cannot be excluded.

the past decade, Iran has enjoyed the status of a so-called threshold state, one that, using its infrastructure and capabilities, could relatively quickly build a nuclear arsenal. However, it should be stressed that Iran has halted its secret military programme (Amad Plan), which envisioned building a still relatively small arsenal of five nuclear warheads.

Today, Iran with its accumulated knowledge, experience, industrial facilities, and fissile materials, could build an arsenal of up to 15-16 uranium-core nuclear weapons. However, according to available information, Iran still is not working on such cores or the serial assembly of warheads, having been content for years with the ambiguity of its current status. It probably hopes that the lack of JCPOA limits and the accumulation of a larger stockpile of 60% highly enriched uranium will eventually force desired concessions from the U.S. and the EU on their economic sanctions.

Following the collapse of the JCPOA nuclear deal in 2018, Iran increased its uranium enrichment levels and quantity many times. It is also slowly perfecting a ballistic missile arsenal with a range of up to 2,000 km. Israel has been Iran's priority target, and within five to 10 years its arsenal could be even capable of reaching all of Europe and the continental U.S. In future, it can build a first-generation nuclear arsenal and within a decade at most of its first nuclear test, Iran could probably also build a thermonuclear arsenal, i.e., warheads with many times greater destructive yield.

Maintaining the current situation and not actively working on warheads gives Iran more flexibility in nuclear negotiations, allowing it in case of perceived dangers or higher necessity to quickly build up a nuclear arsenal. This "virtual arsenal" (i.e., large amount of uranium in various forms) actually deters the U.S. and Israel from implementing any preventive military options. The challenge for the international community (including the IAEA) remains the detection of the moment of possible resumption of work on a covert military programme or overt violations of the NPT at known and declared nuclear centres in Iran.

Iran's current approach could become a long-term strategy were it not for the confrontation with Israel , military weakening of Hezbollah, allied regime collapse in Syria at the end of 2024, and the possibility of tensions with the new Trump administration in 2025. The rise of the Israeli threat and the new U.S. administration's return to the "maximum pressure" policy might therefore push Iran towards a strategic decision on finalising a nuclear arsenal. Moreover, Iran may justify its arsenal by the denuclearisation of Ukraine, Iraq, and Libya, all three of which were then unprotected from Russian aggression or regime change by the U.S.

However, even in the case of a nuclear compromise between Iran and the new U.S. administration, uncertainty about the stability of the regime and the succession of power after politico-religious leader Ali Khamenei might persist. Indeed, the helicopter crash of May 2024 in which President Ebrahim Raisi died increased concerns about Iran's future nuclear strategy as guided by the Supreme Leader, who controls the current scope, shape, and tempo of the nuclear programme. Iran's internal situation also will be linked to the role and influence of the Revolutionary Guards, on whom the country's future leadership may be much more dependent than Khamenei.

A review of the U.S. approaches to date suggest that any deal limiting Iran's nuclear capability will require far-reaching compromises. Most of the alternative approaches have proved to be highly ineffective, while the options for preventive strikes are too risky for the U.S. or Israel. Some of the new president's advisors seem to be interested in resuming the "maximum pressure" policy on Iran, although Trump himself suggested that he could even lift sanctions and achieve some kind of *JCPOA-II* deal that the Biden-Harris administration failed to negotiate.

Europe has fairly limited motivation and capacities to take up initiatives that go totally against the U.S. strategy, essentially subordinated to nuclear issues. The JCPOA when in force showed little potential for Poland and other European states to develop bilateral relations with Iran in the economic sphere. Indeed, Europeans have to realise the potential costs and risks of systemic corruption and the prospect of the reinstatement or further intensification of U.S. sanctions on Iran. Nevertheless, Poland should also prepare for scenarios of a possible collapse or implosion of the regime in Tehran, which would open up much more attractive opportunities for the development of economic cooperation with Iran.

Were it not for concerns about the sum of transatlantic relations under Trump, Poland could already be pursuing a policy based on the assumption that the Iran nuclear issue will be unresolved for many years, and subsequent fluctuations between different U.S. strategic options. The period of the Polish presidency of the EU in the first half of 2025 is likely to coincide with attempts to renew the “maximum pressure” policy or even Trump’s readiness for negotiating a *JCPOA-II* deal with Iran. During this period, Poland will have to react flexibly to Trump’s, Iran’s, and Israel’s steps, and in case of uncoordinated U.S. and EU positions, work to ease tensions against this background.

It is also in Poland’s interest not to see Iran developing and possessing a nuclear arsenal. However, in the short term, Poland’s current policy towards Iran within NATO, the EU, and the UN should be based still on the reality of Iran’s alliance with Russia, to which it is supplying increasing volumes of kamikaze drones, ballistic missiles, and artillery munitions to continue the war with Ukraine. As Iran’s military cooperation with Russia is not a temporary problem, Poland should support further tightening of the EU economic and technological sanctions on Iran and signal to the Iranian government at every occasion that it impinges on any prospects for improved bilateral political, economic, and cultural relations.

Appendix 1: Reconstruction of U.S. and Israeli Intelligence Estimates (1991-2000)

Date	Source	Key Findings
October 1991	CIA (*National Intelligence Estimate*)	Iran's programme is still at an early stage and disorganised. It lacks the expertise and resources to build nuclear weapons. Iran is trying to achieve the capability to produce nuclear fuel and gain technologies to build a nuclear arsenal. It may take 10-15 years (i.e., 2000-2005) for Iran to build its first nuclear device.
November 1991	Israel's Mossad and Aman (anonymous)	Iran has tried to buy HEU and nuclear warheads from Kazakhstan. Iran—with the broad assistance of Pakistan—could build its first nuclear device by the end of the decade (2000).
November 1991	CIA (anonymous)	Iran is seeking to gain a number of technologies necessary to build nuclear weapons, and that could occur within 10-15 years (1996-2001).
November 1992	CIA (Robert Gates)	Iran is seeking a nuclear weapon and could acquire its first nuclear device by 2000 unless the West prevents this scenario.
February 1993	CIA (James Woolsey)	Iran may achieve the capability to build its first nuclear device within a period of 8-10 years (2001-2003). If Iran receives the necessary foreign assistance, it may achieve these capabilities earlier.
Summer 1993	Mossad and Aman (anonymous)	Iran has released all imprisoned nuclear experts since 1988. Iran is not only working on the capabilities to build a nuclear device but also on a 1,280 km range Shahab-3 ballistic missile. A nuclear warhead on this missile could pose an existential threat to Israel.
September 1994	Aman (Gen. Uri Saguy)	Iran may likely assemble its first nuclear device within the next 5-8 years (1999-2000).
September 1994	CIA (James Woolsey)	Iran may acquire nuclear weapons within the next 8-10 years (2002-2004). Foreign assistance may be crucial to the implementation of these plans. Iran is particularly active in seeking fissile materials and technologies from sources in Russia. Iran is also seeking to acquire operational nuclear weapons to achieve its goal much earlier.
February 1996	CIA and DIA	Available intelligence is insufficient to make more precise estimates, but Iran could acquire nuclear weapons by 2000-2003.
April 1996	Government of Israel (Shimon Peres)	Iran may acquire nuclear weapons by 2000.
January 1997	Aman (consultations with the CIA)	Russia may assist Iran in further developing the Shahab-3 ballistic missile, which could threaten Israel.
February 1997	CIA (George Tenet, in talks with Israel)	Iran needs up to 5-10 years to build its first nuclear device (2002-2007).
April 1997	U.S. Department of State's Intelligence and Research Bureau (Robert Einhorn)	The sum of Iran's civilian and military technologies indicates that its nuclear programme is not exclusively for peaceful purposes. Russia and other countries may have made a significant contribution to Iran's nuclear progress so far.
May 1997	Government of Israel (anonymous)	The U.S. pressure on potential technology suppliers could slow down Iran's nuclear programme until the middle of the next decade. Iran could build its first nuclear device by 2005 at the earliest.
November 1999	Government of Israel (anonymous)	If Russia's assistance to Iran is not halted, it will acquire the capabilities to build a nuclear device within a period of 5 years (by 2004).
January 2000	CIA (*Intelligence Assessment*)	Iran is seeking to master nuclear fuel production capabilities and nuclear weapons' technologies. Iran's work on fissile materials may not be well nor fully monitored. It cannot be ruled out that Iran already has the capabilities to build a nuclear arsenal. The uncertainty stems from Iran's secrecy about its nuclear programme, and the new possibilities created by the black market in the post-Soviet states.

Acronyms: Aman – Israel's Military Intelligence, DIA – U.S. Defense Intelligence Agency, Mossad – Israel's civilian intelligence agency. Prepared by the author (no quotations *in extenso*) from sources quoted in: M.A. Piotrowski, "Program nuklearny Iranu w ocenach USA, Izraela i MAEA," *Sprawy Międzynarodowe*, no. 4, 2012, pp. 31-72, and O. Selikar, F. Rezaei, *Iran, Israel, and the United States. The Politics of Counter-Proliferation Intelligence*, Lexington Books, New York-London 2018, pp. 23-55.

Appendix 2: Differences Between the Key Judgements of U.S. Estimates in 2005 and 2007

Issue	Intelligence Assessment (*Memo to Holders NIE*), May 2005	*National Intelligence Estimate*, November/December 2007
Iran's intentions and determination	– Assess with high confidence that Iran currently is determined to develop nuclear weapons despite its international obligations and international pressure, but we do not assess that Iran is immovable.	– Judge with high confidence that in fall 2003, Tehran halted its nuclear weapons program. Judge with high confidence that the halt lasted at least several years. – DOE and the NIC have moderate confidence that the halt to those activities represents a halt to Iran's entire nuclear weapons program. – 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. – Judge with high confidence that the halt was directed primarily in response to increasing international scrutiny and pressure resulting from the exposure of Iran's previously undeclared nuclear work. – Assess with moderate-to-high confidence that Tehran at a minimum is keeping open the option to develop nuclear weapons.
Iran's capabilities to produce fissile materials	– Iran could produce enough fissile material for a weapon by the end of this decade if it were to make more rapid and successful progress than we have seen to date.	– We judge with moderate confidence that the earliest possible date Iran would be technically capable of producing enough highly enriched uranium (HEU) for a weapon is late 2009, but that this is very unlikely. – We judge with moderate confidence Iran probably would be technically capable of producing enough HEU for a weapon sometime during the 2010-2015 time frame. – INR judges that Iran is unlikely to achieve this capability before 2013 because of foreseeable technical and programmatic problems.
Iran's weaponisation capabilities	– We have moderate confidence in projecting when Iran is likely to make a nuclear weapon; – We assess that it is unlikely before early-to-mid next decade (i.e., 2010-2015)	– We judge with moderate confidence that the earliest possible date Iran would be technically capable of producing enough highly enriched uranium (HEU) for a weapon is late 2009, but that this is very unlikely.

Acronyms: DoE – U.S. Department of Energy, INR – Intelligence and Research Bureau of the U.S. Department of State, NIC – National Intelligence Council. Source: National Intelligence Council, "Iran: Nuclear Intentions and Capabilities," *National Intelligence Estimate*, Office of the Director of National Intelligence, Washington DC, November (published in December) 2007, pp. 6-9, available at: www.dni.gov/files/documents/Newsroom/Reports%20and%20Pubs/20071203_relase.pdf. Note: in the original text the order of estimated issues was: intentions, weaponisation, and production of fissile materials by Iran. In the author's opinion, a more clear order, and reflecting the likely steps by Iran, should be as presented in this table: Iran's intentions, then production of fissile materials, and finally weaponisation.

Appendix 3: Comparison of Iran's Programme Before and Under the JCPOA Limits

Problem	Technical issue	Before the JCPOA	Under the JCPOA
Path to uranium fissile material for a nuclear weapon	Number of IR-1 centrifuges	18,472	Reduction to 6,104
	Number of IR-2 centrifuges	1,008	0
	Works on advanced IR centrifuges	Unlimited	Limited for 10 years
	Minimum time for first nuclear device (*breakout time*)	2-3 months	9-12 months
	Amount of 3.67% LEU stock	10 tonnes	Stock reduced to 300 kg over 15 years
	Amount of 20% LEU stock	245.9 kg	No work on LEU above 3.67%
Path to plutonium fissile material for a nuclear weapon	IR-40 HWR-class reactor in Arak	If operational, the IR-40 HWR in Arak could produce 1-2 core(s) for nuclear weapons annually	Rebuilding the reactor's core. Spent fuel transferred outside Iran. Halt of plans for any new HWRs for 15 years
Monitoring and verification by the IAEA	Full explanation of the past "possible military dimension" in Iran's nuclear programme	Lacking or selective cooperation of Iran with the IAEA in this dimension	Iran commits to clarify the IAEA's previous concerns
	Facilities undeclared to the IAEA	Lack of tools to control and investigate Iranian explanations on these	IAEA access to all declared or requested facilities
	The NPT/IAEA safeguard regimes	Lack of implementation by Iran and IAEA monitoring	Commitment by Iran to more intrusive access by the IAEA
	Monitoring and control of uranium ore milling	Lack of access and monitoring by the IAEA	Inspections by the IAEA for a minimum of 25 years
	Centrifuge production facilities for uranium enrichment	Lack of access and monitoring by the IAEA	Inspections by the IAEA for a minimum of 20 years

Complied by the author from visualisations and summaries of key JCPOA text arrangements in: The White House, "Iran Deal Facts," July 2015, www.whitehouse.gov, and G. Allison, "The Iran Nuclear Deal by the Numbers," *The Atlantic*, 3 April 2015, www.theatlantic.com.

Appendix 4: Comparison of Iran's Main Ballistic Missile Parameters

Name	Class	Range	Mass of warhead	Fuel type	Circular Error Probable	Comments
Shahab-1	SRBM	300 km	1 tonne	Liquid	0.7-1 km	Imported R-17 (Scud-B) from the DPRK and Libya, or licensed version.
Shahab-2	SRBM	500 km	730 kg	Liquid	up to 1.5 km	Imported Hawasong-6 (Scud-C) from the DPRK or licensed version.
Qiam-1 (Burkan)	SRBM	800 km	500 kg	Liquid	up to 1 km	Improved variant of the Shahab-2 and Shahab-3. Intensely used by the Yemeni Houthis.
Shahab-3	MRBM	800-1,000 km	0.7-1 tonne	Liquid	up to 2.5 km	Iranian family of licensed DPRK No Dong-1/Hwasong-7. Range might be also 1,200 km. Amad Plan assumed a nuclear-armed version.
Ghadr-1 (Shahab-3M)	MRBM	1,300-1,600 km	750 kg	Liquid	no data	Version of Shahab-3, might be in the arsenals of Hezbollah and the Houthis.
Emad	MRBM	1,600 km	700-750 kg	Liquid	no data	One of the newer versions of the Shahab-3.
Khorramshahr	MRBM	2,000+ km	0.5-1.8 tonne	Liquid	1.5 km	Iranian modification of the Musudan/Hwasong-10 IRBM (DPRK), with heavier conventional or chemical cluster warheads.
Fateh-110	SRBM	300 km	450 kg	Solid	up to 100 m	First variant of the large family of Iranian SRBMs with solid fuel. Licensed production in Syria, likely also in the arsenals of Hezbollah and Russia.
Fateh-313	SRBM	Less than 300-500 km	350 kg	Solid	up to 100 m	A variant of the Fateh-110, likely in the arsenals of Hezbollah and Russia.
Zulfiqar	SRBM	700 km	350 kg	Solid	up to 100 m	Advanced version of the Fateh-110 SRBM, with longer range.
Dezful	MRBM	1,000 km	350 kg	Solid	no data	The latest variant of the Fateh-110/Zulfiqar family of SRBMs.
Sejjil-2	MRBM	2,000+ km	700 kg	Solid	up to 300 m	First model of an Iranian MRBM with solid fuel. With further development it might be used to build IRBMs and deliver a nuclear warhead.

Comments by the author; technical data derived from M. Elleman, *Open Source Analysis of Iran's Missile and UAV Capabilities and Proliferation*, IISS, London, April 2021, p. 17.

GLOSSARY OF KEY TERMS, NOTIONS, AND JARGON

For the sake of precision, below is an alphabetical list of inter-related terms, concepts and jargon in the fields of nuclear and missile technologies used in the main text of the report. Several institutions in Iran and international agreements are included for clarity. At the end of the glossary are the sources used and recommended by the author for further research and studies.

Atom: a basic particle of matter and chemical elements, as a whole electrically neutral. It is composed of a positively charged and high-density nucleus, and a surrounding electron cloud with a negative electrical charge. More than 99.9% of an atom's mass is contained in its tiny nucleus. See also: *atomic number*, *atomic weight*, *isotope*, *neutron*, *proton*.

Atomic bomb (A-bomb, atomic/nuclear weapon, nuclear bomb): in a narrow sense, this is a bomb in which the source of energy is a fission reaction of an atomic nucleus. The term is often used colloquially instead of more precise terms for a nuclear device or nuclear warhead. It is frequently used with a much wider meaning than just an aerial bomb and includes such weapons as a missile's warhead, artillery shells, and mines.

Atomic number (Z): a parameter that specifies the number of protons in the nucleus of an atom of an any given chemical element. Defined as an ordinal number in the periodic table of chemical elements.

Atomic weight (A): the physical quantity defining the weight of an atom in its basic state, expressed in atomic mass units (*u*).

Ballistic missile: a rocket-propelled projectile (with liquid or solid fuel) carrying a warhead to a target along a ballistic trajectory (*col.* a curve). Its flight takes place in three phases: engine-powered boost, passive mid-course, and terminal (descent). The first mass-produced missile was the German V-2 (Aggregat-4), designed by Wernher von Braun's team. Different types of ballistic missiles are included in this glossary.

Beryllium (*Be*): a rare, naturally occurring chemical element found in minerals and gemstones. When artificially obtained, it might be used in metal alloys for a reactor's reflector or the core of a nuclear warhead.

Booster: a device that increases the yield of a fission-based nuclear bomb by adding a small element of fusion. Uses a deuterium-tritium gas mixture to accelerate and amplify the chances of a chain reaction in a boosted atomic bomb. For example, the Fat Man atomic bomb upgraded in the later Mk. 4 version with a booster had a yield of 30-40 kilotonnes (kt) instead of the original 20-22 kt yield. See: *implosion-type bomb*.

Breakout time (*nuclear breakout period*): a term defining the minimum amount of time required to assemble its first nuclear warhead of given country, based on materials available from facilities already known to the IAEA. The nuclear deal with Iran (JCPOA) introduced technical limits, preventing the assembly of a first nuclear device (*breakout time*) to no less than 9-12 months. Several technical criteria and approaches might be used to estimate this time, but real work on a nuclear weapon may require longer than this calculated time. Breakout is also understood more broadly as a breach of the NPT or works on the nuclear arsenal after its formal termination. Its opposite is the *sneak out* scenario, i.e., the use of facilities unknown and hidden to the IAEA without termination of the NPT (Iran tried this approach until 2003, while Iraq, Libya, North Korea, and Syria also followed this course). See: *JCPOA*, *weapons-grade plutonium*, *weapons-grade uranium*, *weaponisation*, *significant quantity*.

Chain reaction: a self-sustaining sequence in which energy and neutrons produced by atomic fission trigger further fission events.

Chic: the U.S. intelligence community's codename for China's nuclear tests. The ground test of Chic-1 (16 October 1964) had a 20-22 kt yield and was based on the Soviet RDS-1 (Joe-1) device design. Chic-4 (27 October 1966) had a 15-20 kt yield and tested a warhead for the Dong Feng-2 ballistic missile.

Cobalt (*Co*, Latin: *cobaltum*): a chemical element found in nature in the form of various minerals. It is used in high-quality alloys and medicine, while the isotope cobalt-60 is obtained artificially in reactors. See: *cobalt bomb*, *isotopes*.

Cobalt bomb: a radiotherapeutic device for gamma irradiation for cancer treatment or food sterilisation, and some other medical research. The military meaning is a hydrogen bomb with a cobalt coating, which when detonated amplifies gamma radiation and prolongs the contamination period. According to Leo Szilard's theory (1950), with the prolonged decay period, cobalt-60 would ultimately eliminate the human species after a global thermonuclear war.

Cold test: a method of testing a nuclear device without triggering a chain reaction and its derivative nuclear explosion. This test requires special preparations and saves expensive Pu-239 or U-235 fissile material. In the jargon of nuclear physicists, it is also called a subcritical test. See: *subcritical mass*, *nuclear test*.

Comprehensive Test-Ban Treaty (CTBT): an international treaty negotiated in 1993-1996, intended to ban any further nuclear tests. It has been signed and ratified by 187 states. Of the 44 states listed in Annex 2 of the CTBT (the terms of its entry into force), the U.S. and China, still have not ratified it, and Russia withdrew its ratification in November 2023. The CTBT Organisation monitors abiding of the treaty through a system of special sensors around the globe. Iran signed this treaty on 24 September 1996 and is listed among the states in Annex 2, but so far has not ratified it.

Core: the main part of a reactor or nuclear bomb that contains the fissile material and initiates a chain reaction. Within a reactor this is usually a grid of fuel and control rods. If the control of the cooling process in a reactor is lost, its core may induce meltdown.

Critical mass: the smallest amount of fissile material necessary to achieve a chain reaction and nuclear explosion. Criticality depends on several factors, i.e., the type of fissile material (U-235 or Pu-239), its shape and mass, purity and density, the use (or absence) of a reflector in the reactor or warhead core. See: *weapons-grade plutonium*, *weapons-grade uranium*.

Cruise missile: a self-propelled, guided and winged missile with variable flight trajectories, a fuselage, and a shape resembling an unmanned aircraft (archaically called a "flying bomb" or "missile-aircraft"). These missiles can be classified according to their platform (ground-, air-, or sea-launched), purpose (sea surface or land targets), and engine type (rocket, turbojet, ramjet, and pulsejet).

Depleted uranium (DU, uranium metal, depletalloy, D-38): a by-product of U-235 enrichment and a mixture of uranium isotopes, mainly (99.7%) U-238 along with negligible amounts of U-235 and U-234. It is 40% less radioactive than natural uranium. DU's high density and ease of processing make it an ideal material in various types of gamma and X-ray shielding. In this form, it is not suitable as a core of a nuclear weapon but is widely used in subcalibre anti-armour projectiles (conventional weapons).

Detonator: a fuse based on a conventional explosive that triggers explosion. A detonator in a nuclear weapon triggers the critical mass of the isotope U-235 or Pu-239 in the core of a nuclear device.

Deuterium (H-2 or D, heavy hydrogen): a stable isotope of hydrogen with one proton and one neutron, found in nature mainly in seawater. It is an essential component of boosted atomic and hydrogen weapons, for example, a 500 kt yield device requires as much as 20 kg of deuterium.

Dirty bomb: a crude device that on exploding contaminates the air and surrounding area with a radioactive dust cloud. It uses isotopes (cobalt, iridium, polonium, or radium) as a coating for a conventional explosive. It is not a nuclear but a radiological weapon, and a weapon of mass destruction (WMD). In counter-terrorism jargon, it is referred as a "radiological dispersal device" (RDD).

Electron (*e*): a subatomic elementary particle with a negative electric charge that orbits in a cloud (orbital) surrounding an atomic nucleus.

European Phased Adaptive Approach (EPAA): a ballistic missile defence system for the area of European NATO countries against missile threats from the Middle East, announced by Barack Obama (17 September 2009). The original concept of the EPAA was based on four phases (reduced to three), corresponding to the expected progress of Iran's ballistic missile programmes and the planned operational capability of the next versions of the U.S. SM-3 interceptors.

Fissile material: an isotope containing atomic nuclei that in collision with neutrons can undergo easy and rapid fission. The most important isotopes are U-235, U-238, and Pu-239. This material is an essential part of a nuclear weapon's core. See: *nuclear fuel*, *plutonium, uranium*.

Gas centrifuge (Zippe-type): a cylindrical device for uranium enrichment, the most common and highly efficient method patented by Gernot Zippe (1956). It uses gaseous uranium hexafluoride (UF6) filling a rapidly rotating centrifuge to separate the isotopes of the lighter U-235 from the heavier U-238. The U-235 isotope remains in the central space of the centrifuge as enriched uranium, while U-238 moves towards its walls as depleted uranium. The gas with U-235 is shuttled to the next centrifuge within a cascade of machines and is further enriched. The main technological challenge is the slow pace of reaching 20% highly enriched uranium (HEU), a level after which the time necessary for reaching the next and higher levels of enrichment is significantly shortened. See: *highly enriched uranium*, *low enriched uranium*.

Ground-based Midcourse Defense (GMD): a missile defence system for the continental United States against the threat of a limited strike with intercontinental ballistic missiles. The system relies on the two Ground-Based Interceptors' (GBI) bases in Alaska and California. It was modified by the Obama administration from architecture of the Clinton-Bush "missile shield" (National Missile Defence, NMD). GMD protects the area of North America, while the EPAA protects the European NATO countries. See: *EPAA*.

Gun-type bomb (gun-type weapon, gun-type device): a crude nuclear device with a relatively low yield of explosion and high consumption of fissile material. Its mechanism involves one part (the "bullet") fired directly into another part of U-235 material. Little Boy, the first atomic bomb dropped on Japan (Hiroshima, 6 August 1945), used as much as 64 kg of highly enriched uranium and achieved a yield of 13-15 kt. Physicists at Los Alamos had more confidence in this solution than in the concept of an implosion-type bomb, hence its use against Japan without a prior test.

Heavy water reactor (HWR): a nuclear reactor in which the moderator is heavy water (HDO or D2O). The HWR class can be used to industrially produce and quickly obtain Pu-239 for nuclear weapons. According to expert estimates, a HWR with power up to 30MW can produce plutonium for 1-2 weapon cores per year, while with power of 400MW one could produce even 10-20 cores per year. See other classes of reactors.

Highly enriched uranium (HEU): uranium with a high content of the U-235 isotope (above 20%), which makes it useful for obtaining weapons-grade uranium and building a nuclear weapon. HEU also has some research, scientific, or medical applications. See: *uranium*, *LEU*.

Hydrogen (*H*, Latin: *hydrogenium*): the lightest and most common chemical element in nature. Hydrogen isotopes D and T are essential for the operation of a thermonuclear weapon. See: *deuterium*, *tritium*, *thermonuclear weapon*.

Implosion-type bomb (implosion weapon, implosion device): a model of nuclear device ("physics package") with fissile material subjected to a high pressure wave from surrounding conventional explosive charges (so-called lenses). The implosion densifies this material, creating the critical mass leading to a chain reaction and nuclear explosion. The first nuclear device, called "Gadget", was used in the "Trinity" test and produced a 20-25 kt yield (Alamogordo test site, 16 July 1945). It was improved as the Fat Man bomb (dropped on Nagasaki, 9 August 1945) and later produced in a short series as the Mk. 3 atomic bomb. The "Nth-Country Experiment" at the Lawrence Radiation Laboratory (1964-1967) demonstrated the feasibility of designing an implosion weapon with a yield up to 10 kt by physics post-doctoral students without prior experience in weaponisation or access to classified information in the field (note, this was not the actual assembly of a nuclear device).

Inter-continental ballistic missile (ICBM): a class of ballistic missile with a range of more than 5,500 km, as defined by U.S. and NATO intelligence.

Intermediate range ballistic missile (IRBM): a class of ballistic missile with a range of 3,000-5,000 km, as defined by U.S. and NATO intelligence.

International Atomic Energy Agency (IAEA): a UN specialised agency based in Vienna responsible for monitoring and verifying safeguards and the peaceful use of nuclear energy in member states. Established on 11 December 1954, 178 states are currently members of the IAEA, and Iran since May 1958.

Islamic Revolutionary Guard Corps (IRGC, Persian: *Sepāh-e Pāsdārān-e Enghelāb-e Eslāmi*): a formation established in 1979 to protect the theocracy in Iran. With the war with Iraq, it was expanded to include more paramilitary and regular military units, with separate branches of forces. The IRGC currently supervises, among other things, its own 200,000-strong regular forces, missile forces, and various military programmes, and even part of the economy of Iran. The IRGC is perceived as the most loyal institution to the regime and an alternative to Iran's regular Armed Forces (Artesh).

Isotopes: atoms of a given chemical element with the same atomic number (number of protons) but with different mass numbers (numbers of neutrons).

Joe: the codename for Soviet nuclear tests within the U.S. intelligence community. *Joe-1* (Russian: RDS-1) tested on 29 August 1949 had a 21 kt yield. Its design was based on the U.S. Fat Man bomb blueprints stolen by Soviet intelligence from the Manhattan Project.

Joint Comprehensive Plan of Action (JCPOA): the P5+1 group and Iran nuclear agreement of 14 July 2015. Negotiated on the basis of the Interim Agreement of 24 November 2013, and the Framework Agreement of 2 April 2015. It is an intergovernmental agreement, and therefore does not require ratification by the U.S. Congress like other treaties. In May 2018, it was terminated by the first Donald Trump administration. It, in essence, limited the scale and improved international monitoring of the nuclear programme of Iran (extending the *breakout time*) in exchange for the lifting of a number of U.S., EU, and UN sanctions introduced in 2006-2012.

Kilotonne (kt): a unit of explosive yield or blast of power used to measure nuclear explosions and which is equivalent to the mass of one thousand tonnes of trinitrotoluene (TNT).

Kim: the codename for North Korea's nuclear tests within the U.S. intelligence community. The Kim-1 test (3 October 2006) may have had some issues with the detonator or the quality of plutonium used, hence the divergent yield estimates of this "dud", most often estimated below 1 kt.

Light water reactor (LWR): a reactor in which the fuel is uranium enriched to the level of 3-5% U-235, and the core moderator is ordinary water (H2O, light water). Due to the extended burning period of the nuclear fuel and the longer time to extract Pu-239, the LWR class is considered to pose a lower risk for any covert production of weapons-grade plutonium. However, this view is contested by some experts, who point to the possibility of plutonium production, which is also the rationale for their monitoring by the IAEA.

Low enriched uranium (LEU): a mixture of U-235 and U-238 isotopes, used mainly in medicine, science, and research. As a nuclear fuel (3-5% LEU) can be used in many types of reactors, especially of LWR class. It is not suitable for a nuclear weapon's core, which requires further enrichment above the 20% level. Some more advanced designs of small research reactors may require uranium enriched to 19.75% LEU, called HALEU (high-assay low enriched uranium). See: *uranium*, *highly enriched uranium*, different classes of reactors.

Manhattan Project (codename the Manhattan Engineer District, MED): a top secret U.S. programme with the assistance of the UK and Canada, dispersed across sites at Berkeley, Chicago, Hanford, Los Alamos, and Oak Ridge. The entire project was led by Gen. Leslie Groves of the U.S. Army Corps of Engineers, with teams of physicists led by Robert J. Oppenheimer. Among many other inventions, the MED developed the first generation of atomic bomb designs, as well as the first methods of uranium enrichment. Several teams of scientists at Los Alamos were deeply penetrated by Soviet intelligence, allowing the USSR to build and test the Joe-1 device. See: *gun-type bomb*, *implosion-type bomb*.

Medium-range ballistic missile (MRBM): a class of ballistic missile with a range of 1,000-3,000 km, as defined by U.S. and NATO intelligence.

Megatonne (MT): a unit of measurement of the yield of a thermonuclear explosive or nuclear explosion equivalent to one million tons of trinitrotoluene (TNT).

Megawatt (MW): a unit of measurement of electrical power and energy flow in power plants, especially nuclear reactors. For reference, 1 MW equals one thousand kilowatts or one million watts.

Missile Technology Control Regime (MTCR): an intergovernmental agreement concluded on 16 April 1987 to control transfers of crucial missile technologies: ballistic and cruise missiles, armed drones, and dual-use materials or components useful for their production. The MTCR defines three categories of equipment and technology under its control. There are 35 signatories of the MTCR. See: *ballistic missile*, *cruise missile*.

Mixed oxide fuel (MOX): nuclear fuel for reactors consisting of a mixture of plutonium and uranium recovered from the nuclear fuel, waste, or bomb cores.

Moderator: a medium in a nuclear reactor that reduces the speed (rate) of the transition of fast neutrons to thermal neutrons, which are more efficient in splitting the atomic nuclei in the nuclear fuel. The best neutron moderators are, in order: heavy water, graphite, beryllium, and ordinary water. See: different classes of reactors.

National Intelligence Estimate (NIE): a secret intelligence report with an expert's best assessment of a selected topic for the U.S. government. An NIE is prepared with contributions from all of the U.S. intelligence community agencies (currently 17), which may express their dissident views in the conclusions of the report. Analytical and editorial work on an NIE may take up to several months, although in an urgent case this can be shortened to several weeks or even a few days (then called Special NIE, SNIE). Depending on new available information or requests from the White House or Congress, the particular report may be updated every few years or supplemented earlier with a shorter report (called a Memorandum to Holders of NIE, MTH). The basic methodology and procedures of the NIE were developed by Sherman Kent, head of the Office and the Board of National Estimates at the CIA (1952-1967).

Neutron (Latin: *neuter*): a subatomic particle that is part of the atomic nucleus and is electrically neutral (has no electric charge).

Neutron bomb (neutron weapon, *clean bomb*): a type of thermonuclear device whose primary destructive power is based on neutron and gamma rays. With a limited shock wave and thermal radiation, it is optimal for attacking enemy troops and civilians. Its lower yield and reduced radiation are less kinetically destructive than classic thermonuclear weapons.

Non-Proliferation Treaty (NPT): an international treaty negotiated in 1965-1968 that entered into force on 5 March 1970. The main purpose of the NPT is to prevent the transfers of nuclear weapons technologies from the P5 states to non-nuclear weapon states (to guarantee "peaceful purposes"). It currently has 190 signatories. India, Israel, and Pakistan have not signed it, and North Korea denounced it in 2003. The IAEA has developed a number of additional agreements and detailed safeguards for verifying compliance with the NPT. Iran signed the treaty on 1 July 1968 and ratified it on 2 February 1970.

NPT Additional Protocol (correctly and formal: The Additional Protocol to a Safeguards Agreement): approved in May 1997 by the IAEA, this is a stand-alone agreement with the member state supplementing the NPT and agency's safeguards. The Protocol significantly expands the agency's authority and tools to inspect and verify safeguards foreseen in the treaty and comprehensive safeguards agreements. It has been signed by 150 states and the European Atomic Energy Community (Euratom). Iran signed it on 18 December 2003, but suspended its obligations on 21 February 2001.

Nuclear device: a very broad term for both nuclear and thermonuclear weapons, as well as for different reactors or nuclear propulsion systems.

Nuclear fission: the split of an atomic nucleus into at least two smaller and similar mass nuclei, it can be spontaneous or artificial. Process discovered by Otto Hahn and Fritz Strassemann, the term was introduced to science by Otto Frish and Lisa Meitner. The opposite of fission is nuclear fusion.

Nuclear fuel: all substances with fissile material, mainly the enriched isotope U-235. In addition to U-235, some reactors can use cheaper fuel based even on natural uranium. Modern fuel for many reactor classes are plutonium and mixed oxide fuel (MOX). The choice of fuel depends on the type of reactor. For the majority of them it is in solid form, like uranium rods. See: *core*, *fissile material*, *reactor*, *MOX*.

Nuclear fuel cycle: the process of producing fissile material for the core of a nuclear reactor or bomb. A full fuel cycle requires mining or importing uranium ore, then milling and converting it into the form for enrichment, and later using it in the core of a reactor, with the option for recovering plutonium from the spent fuel. Uranium-based weapons require a short fuel cycle based on various enrichment methods. Plutonium-based weapons require a full reprocessing cycle. See: *plutonium*, *reprocessing*, *uranium enrichment*.

Nuclear fusion: a reaction involving the fusion of two or more light atomic nuclei (usually deuterium and tritium) into one larger and heavier atom. It is possible thanks to extremely high temperatures, i.e., thermonuclear fusion. Discovery of the process and two-stage design allows the construction of a thermonuclear bomb. See: *clean bomb*, *thermonuclear weapon*.

Nuclear propulsion: a broad term for a system using nuclear energy, mainly by advanced military submarines, cruisers, and air carriers or by specialised civilian vessels like icebreakers. Likely also the most effective and prospective propulsion type for future spaceships.

Nuclear test: a trial of various nuclear devices to confirm their effectiveness and reliability. In the case of nuclear weapons, the tests are classified as atmospheric, ground, underground, underwater, or space. Thanks to modern seismic sensors and inevitable traces in the atmosphere, it is possible to detect most nuclear tests, even those with a minimal yield of 0.5 kt. See: *CTBT*, *cold test*.

P5 (Permanent Five, Primary Five, or Five Powers): jargon for the five permanent members of the UN Security Council and the "recognised nuclear powers", i.e., China, France, Russia (USSR), the United Kingdom, and the United States.

P5+1: jargon for the informal group of the five nuclear powers (P5) and Germany (+1) that has been active since 2006 on issues of limiting, controlling, and sanctioning Iran's nuclear programme.

People's Mojahedin (Mojahedin-e-Khalq Organisation, MKO, Persian: *Sāzemān-e Modżāhedin-e Khalgh-e Irān*, MEK): a leftist-religious group, initially as armed resistance to the monarchy in Iran and later to the Islamic Republic of Iran. Since 1981, its main front organisation among diaspora is the National Council of Resistance of Iran (NCRI), led from France by Mariam Rajavi. Members of the MKO for over two decades received safe haven in Iraq. They are still in conflict with Iranian monarchists. Since 1996, the MKO has been allegedly cooperating with Israeli intelligence. In the summer of 2002, the NCRI exposed to the public Iran's secret nuclear facilities in Arak and Natanz. MKO members may have been involved in some of the assassinations of Iranian nuclear scientists.

Plutonium (*Pu*): a chemical element, a heavy and highly radioactive silver-coloured metal recovered from reactor fuel (in nature, only trace amounts of Pu-233 exist). Most of the 15 known isotopes of plutonium can be used as nuclear fuel, but in practice not all combinations of these are equally effective or economic. Plutonium extracted from spent nuclear fuel typical consists of 55% Pu-239, 23% Pu-240, and up to 12% Pu-241. Adding gallium (0.9-1% of the alloy's weight) to the extracted Pu-239 makes an ideal material for the core of a nuclear weapon.

Proliferation of weapons of mass destruction: spreading or transfer of technologies, knowledge, and/or materials for developing and delivering a biological, chemical, or nuclear weapons system. A number of existing international agreements or treaties aim to limit proliferation of these systems, as well as control dual-use technologies.

Proton (*p*): a subatomic particle that is a component of the atomic nuclei. It is electrically positively charged, and the number of protons in the atom is balanced by electrons.

Reactor: a device for a controlled, slowed, and long-lasting chain reaction without nuclear explosion. Depending on the design, it can use uranium with different levels of enrichment as fuel, along with several types of temperature coolants and reaction moderators. In nature, the equivalents of reactors are a star's core (thermonuclear reactions), but there are also a few naturally formed uranium reactors discovered in geological layers of the earth (Oklo area in Gabon). See: different classes of reactors.

Reactor-grade plutonium (RGPu): plutonium recovered from spent reactor fuel with up to 50-60% Pu-239, up to 24% Pu-240, and 10-15% Pu-241. In the case of rapid fuel consumption in the reactor, these proportions can reach about 40% Pu-239, up to 30% Pu-240, and up to 15% Pu-241 and Pu-242. RGPu is characterised by a higher content of Pu-240, which negatively affects the production of a stable nuclear weapon core. For military purposes, it requires further conversion into weapons-grade plutonium. However, in 1962 the U.S. conducted a 20 kt nuclear test that used reactor-grade plutonium delivered by the United Kingdom, although the exact date and details of this test are still classified in both countries.

Re-entry vehicle (RV): a vehicle of special construction and materials used for the protection of a ballistic missile warhead or spaceship during re-entry into the atmosphere. RVs protect against friction and extremely high temperatures after they enter the terminal phase in Earth's atmosphere. See: *ballistic missile*, *space-launch vehicle*.

Reflector: a layer of material (beryllium-graphite alloy) that surrounds the core of a reactor or weapon, reflecting neutrons back into the core to trigger nuclear fission. The beryllium reflector in a nuclear weapon allows for a reduction in the amount of Pu-239 or U-235 needed in the core.

Reprocessing (nuclear fuel reprocessing): a multi-stage process of extracting plutonium or uranium from spent nuclear fuel. The key step is the chemical method of plutonium and uranium recovery by extraction (PUREX), after which the separated and purified material is metallurgical processed. Due to the high radiation of spent fuel, the reprocessing plants require special chambers and equipment as well as personnel safety protection. Most of the chemicals for plutonium reprocessing are generally available, which necessitates broader monitoring by the IAEA.

Research reactor (RR): a low-power reactor that by its design is not intended for industrial production of electricity or plutonium. This class can vary greatly in design, and are ideal for scientific research or medical isotope production. A variant of the RR are training and teaching reactors. However, RRs with power above 25MW, at the determination of a government with scientists, and over few years, can be used in the covert production of weapons-grade plutonium. See: *WGU*.

Scientific and technical intelligence (S&TI): intelligence analysis of the progress and directions of an adversary's research and development on strategic systems and weapons of mass destruction. The pioneer of this intelligence discipline and Allied successes was the British physicist Reginald V. Jones, who later influenced strongly the development of scientific intelligence in the U.S. Not to be confused with the modern technical means of intelligence, see: *TECHINT*.

Short-range ballistic missile (SRBM): a class of ballistic missile with a range up to 1,000 km, as defined by U.S. and NATO intelligence.

Significant quantity (SQ): an IAEA term referring to the minimum amount of fissile material required to build a single nuclear weapon of crude design. According to the agency, a first-generation atomic weapon requires 8 kg of plutonium or 25 kg of highly enriched uranium.

SQ used by IAEA might also be applied to materials potentially useful in the development of a first device, such as 20 tonnes of thorium, 20 tonnes of depleted uranium, or 75 kg of low enriched uranium. These criteria are questioned by some experts, who argue that the SQ for a 10-20 kt yield weapon should be defined at only 5 kg of plutonium and 13-15 kg of highly enriched uranium. The difference in criteria of the amount of SQ may result in different estimates of the expected threshold of minimal capabilities or time needed to assemble the first nuclear weapon in a particular country. See: *breakout time*, *weaponisation*.

Space launch vehicle (SLV): a rocket-powered system that launches a spaceship or an artificial satellite into space. Mastery of SLV technologies can facilitate the development and covert projects of long-range ballistic missiles of IRBM or ICBM class. The key difference between the two is payload, whether a spaceship vehicle or a warhead re-entry vehicle.

Stuxnet: disclosed in June 2010, it is self-replicating and malicious software for the Windows computer systems (*computer worm*). The U.S. began work on it around 2005, and in 2009-2010 used it to sabotage Iranian gas centrifuge cascade control systems. This joint U.S.-Israeli operation ("Olympic Games") succeeded in disrupting and physically damaging at least 10% of the centrifuges, slowing the pace of uranium enrichment at Natanz.

Subcritical mass: an insufficient amount of fissile material to cause a chain reaction or continue to nuclear explosion. See: *cold test*.

Supercritical mass: an excessive amount of fissile material relative to the critical mass, and only eventually reaching critical mass, fission, and acceleration of secondary chain reactions.

Technical intelligence (TECHINT): initially understood as the collection and analysis of intelligence on the technical capabilities of an adversary. Currently defined as various technical means of intelligence and reconnaissance collection. These are so-called technical disciplines of intelligence (in jargon acronyms ELINT, IMINT, MASINT, NUCINT, RADINT, and SIGINT), separate from the discipline of traditional human intelligence (HUMINT).

Thermonuclear weapon (hydrogen bomb, H-bomb): a nuclear weapon in which the main source of energy and yield of the explosion is a fusion reaction. First tested in the U.S. (Ivy-Mike) with a yield of 10.4 MT (1 November 1952), it is a device designed on the basis of a concept by Edward Teller and Stanisław Ulam. The bigger yield is derived from the second stage of a warhead—so, a two-stage bomb. Theoretically, there is no limit to the yield of thermonuclear weapon, and the most powerful was Soviet RDS-220 (Joe-111, Tsar-Bomba) device reaching a yield of 57-58 MT (17 October 1961).

Tritium (H-3 or T): an unstable isotope of hydrogen with one proton and two neutrons. It occurs naturally in trace amounts in the earth's atmosphere, and is obtained during nuclear fission or fusion. Tritium is an essential ingredient of boosted nuclear and thermonuclear weapons, significantly increasing the yield of their explosions.

Triuranium octoxide (U3O8): the most durable of uranium oxides, obtained from one of the ores' forms—pitchblende. Its concentrate colour might be brown or black (black oxide). In nature, it occurs less frequently as the radioactive crystal mineral uraninite (German: *Pechblende*). Research on uraninite by Maria Curie-Skłodowska and Pierre Curie led to discoveries of polonium and radium (1898). See: *uranium*, *yellowcake*.

Uranium (*U*): a radioactive and natural chemical element in the Earth's crust. It main form is uraninite or uranium pitch (German: *Pechblende*), resembling drops of solidified tar. Natural uranium (NU, Nat-U) is a mixture of three isotopes: U-238 up to 99.3%, U-235 up to 0.7%, and

U-234 in trace amounts. This form of uranium is not suitable for a nuclear weapon without further enrichment. See: *uranium ore*, *triuranium octoxide*, *yellowcake*.

Uranium enrichment: a shorter stage and part of the nuclear fuel cycle using various methods to enrich uranium to higher levels. The aim is to increase the amount of U-235 atoms while reducing the sum of U-238 and U-234 atoms. The Manhattan Project used only two methods—electromagnetic separation and gaseous diffusion. Today, gas centrifuge enrichment and laser separation methods are more efficient and cheaper. Subsequent higher levels of uranium enrichment are defined as percentages with the acronyms LEU, HEU, WGU (see their definitions in this glossary). Economically enriched uranium production is ideal in large industrial plants with thousands of gas centrifuges in hundreds of cascades.

Uranium ore (UO2): minerals with concentrations of natural uranium and other elements. Typical ores are uraninite (commonly found as pitchblende), uranium silicate mineral (rare), brannerite in granite, carnotite, and torbernite (even more rarely found). Each ore requires a specific mining method and chemical processing. In 1942-1945, the U.S. and British efforts focused on securing ore deposits in the Belgian Congo to prevent their capture by Nazi Germany or the Soviet Union. See: *uranium*, *triuranium octoxide*, *yellowcake*.

Weapons-grade plutonium (WGPu): the fissile material in the core of a nuclear weapon, containing up to 93% Pu-239 and up to 6-7% Pu-240, with traces of Pu-241 and Pu-242. WGPu is generally more economic and efficient than weapons-grade uranium and is extracted from reactor-grade plutonium using electromagnetic separators. Due to monitoring of civilian reactors by the IAEA, it is difficult to use these for the covert and rapid production of WGPu sufficient for a weapon core.

Weapons-grade uranium (WGU, WG-HEU): the isotope U-235 highly enriched up to the 85-90% level. Due to its costs, WGU has virtually no civilian or medical applications and is an ideal material for the core of a nuclear weapon or the propulsion system of a large military vessel.

Weaponisation: a term for the entire process of the assembly of the three main components of nuclear weapons, i.e., fissile material, nuclear warhead, and delivery means. Might also be more broadly used to describe all steps from the research and development to testing and production of operational nuclear weapons. In a narrower sense, weaponisation may mean only work on the construction and production of nuclear (as well as biological and chemical) weapons. A nuclear device requires a set of special and safe parts or mechanisms like: re-entry vehicle, the core and fissile material, fuses and detonators, conventional explosives, electric batteries, a neutron generator and reflector.

Yellowcake (urania): the colloquial name for the concentrate obtained during the processing of uranium ores, derived from the yellow colour of the powered product from their grinding and milling. Like natural uranium ore it contains up to 0.7% of the U-235 isotope. As a semi-finished product, yellowcake still requires industrial conversion into gaseous uranium hexafluoride (UF6), and further enrichment until nuclear fuel is produced. See: *uranium*, *triuranium octoxide*.

Sources and Recommended Reading:

– R.M. Clark, *The Technical Collection of Intelligence*, Congressional Quarterly Press Inc., Washington DC 2011.
– Th.B. Cochran, Ch.E. Paine, *The Amount of Plutonium and Highly-Enriched Uranium Needed for Pure Fission Nuclear Weapons*, Natural Resources Defense Council, Washington DC, 13 April 1995.

– S. Fetter et al., "Fissile Materials and Weapons Design," *Science and Global Security*, vol. 1, no. 3-4, 1990.
– B.T. Goodwin, *Nuclear Weapons Technology 101 for Policy Wonks*, Lawrence Livermore National Laboratory, Livermore CA 2021.
– L. Dobrzyński, K. Zuchowicz, *Energetyka jądrowa: spotkanie pierwsze*, Narodowe Centrum Badań Jądrowych, Świerk 2012.
– R. Harney et al., "Anatomy of a Project to Produce a First Nuclear Weapon," *Science and Global Security*, tom 14, nr. 2-3, s. 163-182.
– S. Henderson, O. Heinonen, *Nuclear Iran: A Glossary (revised and updated)*, Washington Institute for Near East Policy-Harvard University's Belfer Center for Science and International Affairs, Washington DC 2015.
– *International Atomic Energy Agency Safeguards Glossary 2001 Edition*, International Atomic Energy Agency, Vienna 2002.
– G.S. Jones, "Reactor-Grade Plutonium and Nuclear Weapons: Ending the Debate," *The Nonproliferation Review*, vol. 26, no. 1-2, 2019.
– R. Kokoski, *Technology and Proliferation of Nuclear Weapons*, Stockholm International Peace Research Institute-Oxford University Press, Stockholm-Oxford 1995.
– K. Król, *Bezpieczeństwo radiologiczne*, Wydawnictwo Naukowe PWN, Warszawa 2024.
– J. Kubowski, *Broń jądrowa: fizyka, budowa, działanie, skutki, historia*, Wydawnictwa Naukowo-Techniczne, Warszawa 2008.
– R. Kupiecki (ed.), *Obrona przeciwrakietowa w polskiej perspektywie*, Wydawnictwo Polskiego Instytutu Spraw Międzynarodowych, Warszawa 2015.
– V. Narang, *Seeking the Bomb: Strategies of Nuclear Proliferation*, Princeton University Press, Princeton NJ 2022.
– Office of Technology Assessment, *Technologies Underlying Weapons of Mass Destruction*, U.S. Congress-U.S. Government Printing Office, Washington DC 1993.
– Th. C. Reed, D.B. Stillman, *The Nuclear Express. A Political History of The Bomb and Its Proliferation*, Zenith Press, Minneapolis MI 2009.
– J.T. Richelson, *Spying on the Bomb. American Nuclear Intelligence from Nazi Germany to Iran and North Korea*, W.W. Norton & Co., New York 2007.
– D. Stober, "No Experience Necessary," *Bulletin of the Atomic Scientists*, vol. 59, issue 2, 2003.

POLSKI INSTYTUT SPRAW MIĘDZYNARODOWYCH
THE POLISH INSTITUTE OF INTERNATIONAL AFFAIRS

The Polish Institute of International Affairs (PISM) is a leading Central European think tank that positions itself between the world of politics and independent analysis. PISM provides analytical support to decision-makers and diplomats, initiates public debate and disseminates expert knowledge about contemporary international relations. The work of PISM is guided by the conviction that the decision-making process in international relations should be based on knowledge that comes from reliable and valid research.

POLSKI INSTYTUT SPRAW MIĘDZYNARODOWYCH
THE POLISH INSTITUTE OF INTERNATIONAL AFFAIRS
UL. WARECKA 1A, 00-950 WARSZAWA
TEL. (+48) 22 556 80 00
FAKS (+48) 22 556 80 99
PISM@PISM.PL
WWW.PISM.PL