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WOULD AIR STRIKES WORK?

Understanding Iran's nuclear programme and the possible consequences of a military strike

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With a foreword by Hans Blix

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Foreword

The ultimate aim of the 1968 Non-Proliferation Treaty was a nuclear-weapon free world. All states without non-nuclear weapons were invited to commit themselves to remain without these weapons and the five states, which had tested such weapons, were invited to commit themselves to nuclear disarmament.

"armed attacks on Iran would very likely lead to the result they were meant to avoid"

Incentives to acquire nuclear weapons flow in most cases from perceived security interests or from a wish for recognition and status. Success in preventing a spread of the weapons and in eliminating existing arsenals depends on states coming to the conclusion that their security interests and status do not call for nuclear weapons.

The end of the Cold War has been and remains singularly helpful to lower tensions and to increase security in many parts of the world. Practical cooperation between states bilaterally, regionally or through international organisations has the same effect. By contrast, new nuclear arms programs in nuclear weapon states, anti missile programs, space weapon developments and threats of armed attacks or of actions to bring about regime change through armed force or subversion, increase security concerns. In cases like North Korea and Iran it is not the threat or use of armed force but the absence thereof that will help to ensure non-proliferation.

This report does not reject the contention that a wish to develop nuclear weapons or at least the option to acquire such weapons may be part of the reason for Iran's program for the enrichment of uranium. Today, it does not matter much what the Iranian intention is, if, indeed, there is an agreed intention. After all, whatever the intention today, it could change in two years time. Inducing Iran to suspend the enrichment program at least for a prolonged period of time would – all agree – be desirable to reduce tensions in the Middle East and to give time for other efforts with the same aim. The question is how to induce Iran to join this conclusion.

With much technical knowledge this study argues, that it would be several years before the present Iranian programs for the enrichment of uranium and possible production of plutonium could result in weapons and that there is time for diplomacy. It further argues that military attacks on Iranian nuclear installations would be disastrous and counterproductive. I fully agree.

In the case of Iraq, the armed action launched aimed to eliminate weapons of mass destruction – that did not exist. It led to tragedy and regional turmoil. In the case of Iran armed action would be aimed at intentions – that may or may not exist. However, the same result – tragedy and regional turmoil – would inevitably follow. Further, as argued in this study, armed attacks on Iran would very likely lead to the result they were meant to avoid – the building of nuclear weapons within few years.

It is inconceivable that the Security Council would authorise armed action against alleged intentions. Such action would therefore present another contravention of the UN Charter, raising the question whether anything was left of the Charter's provisions on the threat and use of force. If Iranian nuclear power plants at Bushehr were to be targeted, when they have begun to operate, such attacks would also violate the 1977 Additional Geneva Protocol (Art.56), which protects such plants.

The conclusion is clear: diplomacy must be used to persuade Iran at least to suspend its enrichment program for a prolonged period of time. However, it is illogical to ask Iran to suspend its enrichment programme before any diplomatic negotiations take place about the conditions for the suspension. It is time for serious talk – not for humiliating preconditions.

Hans Blix, Chairman of the Weapons of Mass Destruction Commission
14 February 2007, Stockholm

Executive summary

Far from setting back Iran's nuclear programme, a military attack might create the political conditions in which Iran could accelerate its nuclear weapons programme. This is the conclusion of this detailed analysis of Iran's nuclear programme, which adds further weight to the case that diplomacy must be made to work.

To date, the International Atomic Energy Agency (IAEA) has been unable to confirm or rule out allegations that Iran has ambitions to become a nuclear weapons power. Uncertainty as to the extent of Iran's nuclear programme and Iran's advances towards mastering the enrichment process has led some in the US and Israeli administrations to argue that military action must be taken before it is too late. Advocates of early military action argue that the consequences of a nuclear-armed Iran are such that military strikes are justified, whether a smoking gun is found or not.

But what would be the effect of military strikes on Iranian nuclear facilities? Could they really buy a significant amount of time? And is it possible that Iran could construct a crash nuclear programme in the aftermath of an attack?

This report provides a detailed briefing on the Iranian nuclear programme as well as a breakdown of individual facilities. It sets out the paths open to Iran should it wish to pursue a nuclear weapon capability. It argues that, alongside other regional powers such as Saudi Arabia and Egypt, it is reasonable to assume that Iran has conducted research and development into the fabrication of nuclear weapons. However, there is no evidence to suggest that Iran has embarked on production engineering – putting in place the technical facilities needed to build a bomb – and it is known that it is some way off being able to produce the amount of fissile material needed to produce a nuclear weapon.

Among advocates for military action are those who argue that only by setting back the Iranian nuclear programme militarily will it be possible to ensure that Iran does not master the enrichment process and thereby attain all the knowledge necessary to produce a nuclear arsenal, should it choose to do so.

Based on an analysis of Iran's current programme, this report argues that there is still time to allow diplomacy to work. Furthermore, the case for military action must be assessed carefully. The contention that military action will set back Iran's nuclear programme significantly can and should be questioned.

Questioning the case for military action

Iran's nuclear programme is extensive and dispersed; a military strike would have to contend with:

- A large number of targets;
- Well-protected and hidden facilities;
- Inadequate intelligence; and
- The likely survival of key scientists and technicians.

If the aim of military strikes is to destroy key nuclear facilities, they would have to target: the Kalaye Electric Company that produces components for gas centrifuges; the nuclear power reactor at Bushehr; the heavy-water reactor under construction and the heavy water production plant at Arak; the uranium enrichment facilities at Natanz, the uranium mines and mills at Saghand and the research reactors at Isfahan.

There is an inherent contradiction in arguments that a military strike could both encompass all key facilities and be surgical and brief. A compromise would have to be made on either the scale or military action or the certainty of success. In either case, the numbers of innocent civilian casualties would probably be high because a surprise attack would catch many people unawares and unprotected.

There is a real possibility that Iran has constructed secret facilities in the anticipation of a military strike. It is also conceivable that Iran has built false targets, installations that appear to hold nuclear facilities but in fact act as decoys. With inadequate intelligence, it is unlikely that it would be possible to identify and subsequently destroy the number of targets needed to set back Iran's nuclear programme for a significant period. Furthermore, with the probable survival of key scientific personnel, it would only be a matter of time before Iran could rebuild its nuclear programme. The question is, how much time?

Crash reconstruction

If Iran's nuclear facilities were severely damaged during an attack, it is possible that Iran could embark on a crash programme to make one nuclear weapon. In the aftermath of an attack, it is likely that popular support for an Iranian nuclear weapon capability would increase; bolstering the position of hardliners and strengthening arguments that Iran must possess a nuclear deterrent. Furthermore, Iran has threatened to withdraw from the NPT and, should it do so post-attack, would build a clandestine programme free of international inspection and control.

"It is a mistake to believe that Iran can be deterred from attaining a nuclear weapons capability by bombing its facilities"

In the aftermath of an attack, following a political decision to change the nature of the nuclear programme to construct a bomb as quickly as possible, Iran could:

1. Used stored, fresh nuclear fuel to produce HEU in a small centrifuge facility to fabricate a weapon.
2. Chemically remove plutonium from irradiated reactor fuel elements - from the Bushehr or Arak reactors, if either were operational - and use it to fabricate a nuclear weapon.
3. Assemble new centrifuges and produce highly enriched uranium (HEU). Some centrifuges might survive a military attack, but it is conceivable that Iran has stored additional centrifuges in secure locations.

This process would be hastened if Iran had a secret supply of uranium hexafluoride or if it had constructed a small primitive reactor, fuelled with natural uranium, to produce plutonium for nuclear weapons. It is also possible that, post-attack, Iran could purchase additional needed materials from sympathetic states or on the black-market.

In the aftermath of a military strike, if Iran devoted maximum effort and resources to building one nuclear bomb, it could achieve this in a relatively short amount of time: some months rather than years. The argument that military strikes would buy time is flawed. It does not take into account the time already available to pursue diplomacy; it inflates the likelihood of military success and underplays the possibility of hardened Iranian determination leading to a crash nuclear programme. Post military attacks, it is possible that Iran would be able to build a nuclear weapon and would then wield one in an environment of incalculably greater hostility.

It is a mistake to believe that Iran can be deterred from attaining a nuclear weapons capability by bombing its facilities, and presumably continuing to do so should Iran then reconstitute its programme.

Introduction

There is continuous speculation as to whether the US or Israel might launch military attacks against Iranian nuclear facilities. Though this might not become an imminent possibility for some time, the opportunity to assess the reasoning behind this position – from a scientific point of view – must be taken. This report provides a detailed account of known Iranian nuclear facilities and assessing what facilities would have to be destroyed in order to cut off possible routes to a nuclear weapon. It then weighs up the chances that military strikes could actually achieve the goal of significantly setting back Iran's nuclear programme.

The IAEA has repeatedly stated that it is unable to confirm categorically that Iran is not moving towards a nuclear weapon capability. This level of uncertainty has precipitated calls for military strikes based on worst-case scenario planning. This report unpicks the rationale for military strikes and questions whether there could be any certainty as to fate of Iranian nuclear activities post-military action.

1. Iran's nuclear programme

1.1 Origins

The origins of Iran's nuclear programme date back to under the Shah when, in 1959, Iran purchased a research reactor from the United States. Iran signed the Nuclear Non-Proliferation Treaty (NPT) in 1968 and ratified it in 1970. Having established Iran's Atomic Energy Agency, Shah Mohammad Pahlavi planned to construct up to 23 nuclear power stations across Iran by 2000 with American assistance. The location of the first nuclear plant was to be Bushehr;[1] it was to supply electricity to the city of Shiraz. In 1975, the German firm Kraftwerk Union signed a contract to build two 1,200 MWe nuclear reactors at Bushehr to be completed in 1981.[2]

"Iran has very large oil and gas reserves prompting many to question why Iran needs nuclear power."

After the 1979 Revolution, Iran told the International Atomic Energy Agency (IAEA) that it planned to restart its nuclear-energy programme using nuclear fuel produced indigenously. In January 1979, Kraftwerk Union stopped construction work leaving one reactor 50% complete and the other reactor 85% complete. However, both reactors were severely damaged when, between 1984 and 1988 in the Iran-Iraq war, the Bushehr reactors were bombed repeatedly by Iraq.

In 1995, Iran signed a contract with Russia to resume work on the Bushehr plant, installing a 915-MWe VVER-1000 pressurized water reactor. The contract for the reactor sets the date of delivery to be no later than 19 March 2004. However, there have been significant delays, possibly caused by American pressure on the Russians to stall delivery. The Russians have announced that Bushehr will not be operational until November 2007. It was expected that fuel would will be delivered in March or April,[3] but has recently been delayed once again.

1.2 Civil nuclear programme

Today, Iran's civil nuclear plans – to build seven nuclear power reactors, with a total generating capacity of about 7,000 megawatts of electricity – are regarded as ambitious. Iran has very large oil and gas reserves prompting many to question why Iran needs nuclear power.

Since the time of the Shah, Iran has argued that it needs nuclear power to satisfy increasing demands for electricity. Its energy needs are rising faster than its ability to meet them. Driven by a young population and high oil revenues, Iran's power consumption is growing by around seven per cent annually and its capacity must nearly triple over the next fifteen years to meet projected demand. Iran insists that it needs to sell its oil to obtain foreign currency, pointing out that its oil reserves are finite and that nuclear power is a sensible investment for the future.

Many western observers remain unconvinced that a large civil nuclear energy programme makes much economic sense for Iran. Nevertheless, Iran has repeatedly emphasised that its nuclear programme is entirely peaceful. For example, on 29 April 2003, Iran's Deputy Foreign Minister for Legal and International Affairs, G. Ali Khoshroo, stated that Iran considers "the acquiring, development and use of nuclear weapons inhuman, immoral, illegal and against our basic principles. They have no place in Iran's defense doctrine."[4]

The Iranians also insist that they have an absolute right to develop and use peaceful nuclear technology as spelt out in Article IV of the NPT. Article IV states that:

> *"Nothing in this Treaty shall be interpreted as affecting the inalienable right of all the Parties to the Treaty to develop research, production and use of nuclear energy for peaceful purposes without discrimination... All the Parties to the Treaty undertake to facilitate, and have the right to participate in, the fullest possible exchange of equipment, materials and scientific and technological information for the peaceful uses of nuclear energy."* [5]

1.3 Grounds for suspicion

Despite Iran's denials, many states suspect that Iran is pursuing nuclear weapons. Iran's behaviour has triggered alarm bells. The IAEA has confirmed that,[6] while a Party to the NPT, Iran has:

- Imported uranium hexafluoride gas to test gas centrifuges at the Kalaye Electric Company, thereby producing some enriched uranium;
- Produced uranium dioxide, uranium hexafluoride and a number of other uranium compounds using imported uranium dioxide;
- Produced uranium dioxide targets at the Esfahan Nuclear Technology Centre (ENTC) and irradiated them in the Tehran Research Reactor (TRR) the targets were then processed in hot cells to separate the plutonium; and
- Imported uranium metal for use in laser enrichment.

Iran violated its Safeguards Agreement with the IAEA, required by the NPT, by failing to report many of these activities to the Agency. None of these activities are illegal in themselves; it is the failure to report them to the IAEA that contravenes safeguard agreements and this has fuelled suspicion over Iran's intentions.

"it is the failure to report them to the IAEA that contravenes safeguard agreements and this has fuelled suspicion over Iran's intentions."

Furthermore, like any country with considerable experience in nuclear physics and engineering, having operated nuclear research reactors for decades, Iran has a cadre of trained personnel whose skills could be utilised in a nuclear weapons programme. This combination – of a dubious track record and access to vital human resources – sustains concern over Iran's nuclear activities.

1.4 Possible routes to a nuclear weapon

The nuclear technologies used in a civil nuclear programme are identical to those used in a military nuclear programme. As the Swedish Nobel Prize winning nuclear physicist Hannes Alven remarked: "the peace atom and the military atom are Siamese twins".[7] Eventually, Iran hopes to operate a full nuclear fuel cycle, prompting concerns that this will give Iran all the know-how it needs to develop a military programme.

To date, Iran does not have the fissile material – highly enriched uranium (HEU) or plutonium – needed to produce nuclear weapons. Iran could produce fissile material in three ways:

(1) Highly enriched uranium (HEU) from the gas centrifuge plant in Natanz
Iran has announced that it is producing low enriched uranium using gas centrifuges. It claims that this uranium will be used for fuel in nuclear-power reactors. But, by recycling uranium hexafluoride gas in the gas centrifuges, it is possible that Iran could increase the concentration of the uranium-235 isotope in the uranium to over 90%, suitable for use in nuclear weapons. For use as nuclear fuel, the concentration is about 3.5% (see Appendix I).

(2) Plutonium from the planned heavy water research reactor at Arak
Plutonium would have to be removed chemically from the fuel elements and could then be used to fabricate nuclear weapons (see Appendix II). A heavy-water reactor is a particularly efficient way of producing plutonium for use in very effective nuclear weapons. The reactor at Dimona, Israel, was used to produce plutonium for Israel's nuclear weapons and is the same type of reactor as the one planned at Arak. Iran has recently completed a plant to produce heavy water for the Arak reactor but the reactor itself will not be completed until around 2011.

(3) Plutonium from the nuclear-power reactor at Bushehr
Bushehr is due to become operational in November 2007. Once it is operational, Plutonium could be chemically removed from the fuel elements that have been irradiated in the nuclear-power reactor. The reactor uses uranium dioxide nuclear fuel. Plutonium is produced as the uranium fuel is used up. The plutonium could be used to fabricate nuclear weapons (see Appendix II).

Having concealed the existence of these components of their nuclear programme, the Iranian government has since acknowledged their existence, but insists that they are all part of its civil nuclear programme.

1.5 The Natanz uranium-enrichment facility
Using the yellow cake produced at the Uranium Conversion Facility at Isfahan (see below), uranium is enriched at the Natanz Uranium Enrichment Facility using gas centrifuges. Eventually, nuclear fuel pellets will be produced in Natanz and these pellets will be used to form fuel rods for nuclear-power reactors.

Iran is constructing two gas centrifuge plants at Natanz, 40 kilometres from Kashan. One is a Pilot Fuel Enrichment Plant (PFEP) and the other is a large commercial-scale Fuel Enrichment Plant (FEP). Iran has acknowledged that components for gas centrifuges have been produced and tested in the workshop of the Kalaye Electric Company in Tehran.[8]

The PFEP started up in June 2003 but was shut down when, in December 2003, Iran suspended enrichment activities. Following a break down in diplomatic negotiations, Iran resumed enrichment-related activities in February 2006, including the testing of a 10-centrifuge cascade with uranium hexafluoride.[9] This small-scale enrichment of uranium was conducted under IAEA safeguards. Upon completion, the PFEP will contain about 1,000 centrifuges. On 11 April 2006, Iranian officials announced that uranium had been enriched at Natanz to a concentration of 3.5% in uranium-235 in a cascade of 164 gas centrifuges.[10]

In December 2003, construction of the FEP was also suspended. In April 2006, following the resumption of enrichment, Iran announced that it planned to install 3,000 centrifuges. The plant is being constructed partly underground. Iran has announced plans to install eventually more than 50,000 centrifuges at the FEP.

The capacity of a gas centrifuge is measured in 'separative work units' (SWUs). In the short-term, Iran is likely to utilise the P-1 centrifuge. A reasonable estimate is that each centrifuge of this type would have a capacity of about 2.5 SWU per year, or about 0.013 kg of HEU a year. However, Iran is reportedly experimenting with the P-2 type gas centrifuge (P-2 centrifuges are operated by Brazil, Pakistan and India). The P-2 centrifuges may be about twice as efficient as the P-1 type, with a capacity of about 5 SWU per year. For the sake of comparison, the capacity of centrifuges operated by the European company URENCO is 40 SWU and the capacity of those operated by American enrichment companies is 300 SWUs.[11]

An Iranian facility containing, say, 3,000 P-1 centrifuges could produce 7,500 SWU per year or about 40 kg of HEU per year. With sufficient expertise in HEU-based nuclear weapons, 40 kg per year could provide two nuclear weapons. Iran would need to construct many thousands of gas centrifuges to produce enough HEU to build a strategically significant number of nuclear weapons – for example, five or six weapons, comparable to South Africa's former arsenal.

Building and operating effectively a gas centrifuge facility of a useful size is an industrial undertaking. Given Iran's current technological capability, it is reasonable to assume that about 60% of the centrifuges would have to be rejected as sub-standard; Iran would need to produce approximately 5,000 centrifuges for the facility.[12] Moreover, gas centrifuges break down frequently because of mechanical stress and Iran would need to secure access to a steady supply of replacement machines. Both these factors could contribute to delays. Iran is unlikely even to begin producing the amount of HEU required for the production of a nuclear weapon for at least another five years.

"Iran is unlikely even to begin producing the amount of HEU required for the production of a nuclear weapon for at least another five years."

Before Iran can succeed in producing a significant quantity of HEU, a difficult technical problem will have to be overcome. Iranian uranium is reportedly contaminated with significant amounts of molybdenum and other heavy metals.[13] These impurities could condense and block pipes and valves in the gas centrifuges. In spite of this problem, the Iranians should be able to enrich uranium to the low enrichment needed for civil nuclear-power reactor fuel. But they would not be able to enrich above about 20% in uranium-235. Therefore, Iran would not be able to produce uranium enriched enough for use in nuclear weapons unless most of the molybdenum was removed. If Iran sought to solve this problem promptly, it is likely it would need foreign technical help – for example, from China or Russia. Without foreign assistance, this problem could cause additional delays.

For this reason, if the Iranians take the decision to build a nuclear-weapon force, they may decide to wait until the IR-40 heavy water reactor at Arak is operating and use the plutonium produced there to build nuclear weapons. The Iranians would only need about five kg of plutonium to produce a nuclear weapon whereas they would need about four times as much HEU for the same purpose. The Arak reactor is not expected to be operational until 2011.[14]

1.6 The Arak heavy-water research reactor (the IR-40 reactor)

Iran plans to replace the aged (35-year old) Tehran Research Reactor by building a new heavy water reactor, the IR-40, at Arak. The IR-40 will be a 40-megawatt (thermal) reactor cooled with heavy water and fuelled with natural uranium. According to the IAEA, Iran plans to manufacture the fuel (uranium dioxide) elements for the IR-40 in the Fuel Manufacturing Plant (FMP) to be built at the Esfahan establishment. Iran says that the purpose of the IR-40 reactor is the production of radioactive isotopes for medical and industrial uses.[15]

IR-40 could produce about eight kg of plutonium annually, enough to fabricate two nuclear weapons a year. However, plutonium from the Arak research reactor is unlikely to be available before about 2014.[16]

Initially, 85 tonnes of heavy water will be required for IR-40 but less than one tonne will be needed annually after that. Iran has constructed a heavy water production plant at Khondab, near Arak, with an initial capacity of producing eight tonnes of heavy water per year. Reportedly, a second production plant with a similar capacity is under construction.[17]

1.7 The Bushehr nuclear-power reactor

The Russians have essentially completed the 1,000 megawatt-electrical light-water reactor, of the Russian VVER type, at Bushehr, Halileh. According to Sergei Kiriyenko, head of Russia's Atomic Energy Agency, the reactor is scheduled to start up in September 2007:

> *"A realistic deadline [for transmitting power to the grid] is November 2007. This means a physical start-up [of the reactor] in September and the dispatch of fuel … six months earlier, that means March or April."*[18]

The Bushehr reactor will use low enriched uranium (about 3.5%in uranium-235) as fuel. The core of the reactor will hold about 103 tonnes of uranium contained in 193 fuel assemblies. If operated to generate electricity, the Bushehr reactor will produce about 250 kg of plutonium per year.[19] If diverted for military use, this amount of plutonium would be enough to build between 40 and 50 nuclear weapons a year.[20] There would be enough plutonium in four irradiated fuel assemblies to produce a nuclear weapon.[21]

Under the contract between Iran and Russia, Russia will provide the fuel for the lifetime of the reactor but will take back to Russia all the spent fuel for storage and possibly reprocessing. A possible risk remains due to the fact that Iran would be technically capable of removing the plutonium from spent reactor fuel if it chose to do so. But to do so, they would have to conceal activities from the Russians or proceed with some Russian engineers' or technicians' knowledge.

According to Iran, the Bushehr reactor is the first of a series of six power reactors planned to generate 6,000 megawatts of electricity. It is reported that Iran intends to build a second power reactor at the Bushehr site of a similar type, again with Russian assistance.[22] Iran continues to argue that it is interested in establishing a capability to produce low-enriched uranium so that it has an indigenous supply of nuclear reactor fuel for its reactors and the possibility of export to other countries.

1.8 Additional Iranian nuclear facilities

1. Saghand, 200 kilometres (120 miles) from Yazd, is the location of Iran's first uranium ore mines that became operational recently. Uranium is mined from a depth of 350 metres (1160 feet). The Saghand deposit reportedly contains about 5,000 tonnes of uranium reserves, spread over an area of roughly 130 square kilometres.[23]

2. In the Ardekan Nuclear Fuel Unit, in Ardekan near Yazd, yellowcake (U308) is prepared from the uranium mined at Saghand.

3. At Esfahan, a Uranium Conversion Facility (UCF) converts yellowcake into uranium dioxide. This is in turn converted into uranium hexafluoride gas for enrichment at Natanz. UCF also produces other uranium compounds, including uranium dioxide (UO2) and metallic uranium. This is the fuel fabrication part of Iran's nuclear fuel cycle. There is a Zirconium Production Plant nearby that produces ingredients and alloys for nuclear reactors.

4. In 2000, a pilot plant for Laser isotope separation (LIS) was established in Lashkar Ab'ad (see Appendix 3). LIS offers highly efficient uranium enrichment and is relatively cheap to operate. The Iranians claim the laboratory was dismantled in 2003.[24] However, Alireza Jafarzadeh, an Iranian opposition figure from the Mujahideen-e-Khalq Organization (MKO), who has exposed clandestine facilities in the past, claimed that Iran has recently revived the LIS programme. Iranian officials dismissed the allegation as "baseless and unfounded".[25] Given the progress Iran has made in gas centrifuge technology, it is not thought that laser enrichment would be the method of choice for producing significant amounts of HEU. It is possible, however, that Iran might continue to pursue this method as a back-up option.

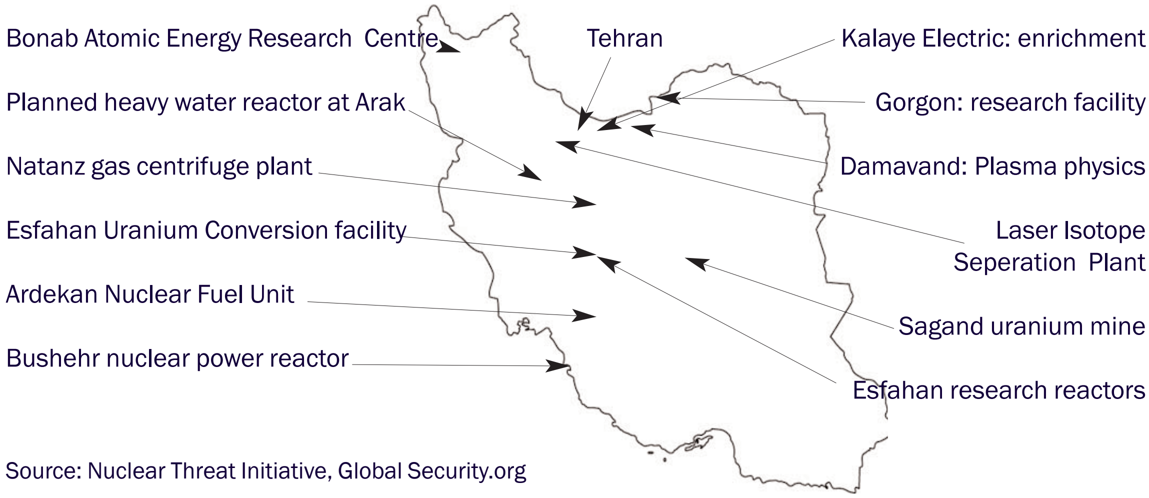
5. The Bonab Atomic Energy Research Center is a facility to investigate applications of nuclear energy and technology to agriculture. There is also a Center for Agricultural Research and Nuclear Medicine at Hashtgerd, Karaj.

6. Iran operates four small research reactors – three, supplied by China, at the Estahan Nuclear Technology Centre in Tehran and one, supplied by the USA, at the Nuclear Research Centre in Tehran. Two of the three at Estahan are sub-critical assemblies used for training nuclear physicists and technicians; they have both been operating since 1992. The third at Estahan is a 30-kilowatt research reactor used for research purposes; it has been operating since 1994. The fourth is a five megawatt-thermal reactor also used for research; it has been operating since 1967, an indication of how long Iran has been interested in nuclear technology.

1.9 Conclusions

If Iran does intend to fabricate nuclear weapons, it is likely that it would use HEU (produced by gas centrifuges) as the fissile material in the short-term. Of the three routes discussed in this chapter, the production of HEU is thought to be the quickest route to building a nuclear bomb. The production of plutonium from the Arak heavy-water reactor is also a possible route but would take much longer as Arak is not expected to be able to produce plutonium until 2014. Given the involvement of the Russian government, the least likely route is the use of plutonium produced in the Bushehr reactor. In the longer term, using plutonium from the Arak reactor could be the optimal route to nuclear weapons or via the dual production of HEU and plutonium (with laser enrichment as a possible back-up option).

Some known Iranian nuclear facilities and related centres



Source: Nuclear Threat Initiative, Global Security.org

2 Iran's nuclear capabilities

"All the nuclear material declared by Iran to the [IAEA] has been accounted for - and, apart from the small quantities previously reported to the Board, there have been no further findings of undeclared nuclear material in Iran. But, because of the inability of the Agency to make progress in resolving the outstanding issues relevant to the scope and nature of Iran's current and past centrifuge enrichment programme, the Agency cannot make any further progress in its efforts to provide assurances about the absence of undeclared nuclear material and activities in Iran."

Mohamed el Baradei, Director General, IAEA[26]

"the onus for increased transparency is on Iran."

Based on evidence currently available, it is neither possible to prove or completely rule out allegations that Iran has ambitions to become a nuclear weapons power. Iran has proved unwilling to employ measures going beyond those prescribed by the relevant safeguards agreement. Increased transparency would help gain the trust of the international community; the onus for increased transparency is on Iran. Without this, there will continue to be speculation as to whether Iran has started developing a nuclear weapons programme.

2.1 Building a nuclear weapon

In general, the development of new nuclear weapons can be described in six separate stages:

1. Concept
This involves the design of possible types of weapons, with information gleaned from open and often covert sources, followed by a feasibility study.

2. Prototype design
Paper and computer studies are conducted to test feasibility further but not directed towards production.

3. Choice of design
A design is chosen and defined with a view to production.

4. Development engineering
A detailed design for production is created using computer simulation, non-nuclear and nuclear testing.

5. Production engineering
The stage in which all tools, equipment and skills are brought together to create the engineering systems needed to build a nuclear weapon.

6. Production of nuclear weapon
The actual manufacture of a nuclear weapon.

Before stage five, non-nuclear experiments will be undertaken to develop implosion technology using conventional high explosives to compress a sphere (or a series of concentric spherical shells) of HEU or plutonium or both, into a super-critical mass (so that it gives a nuclear explosion). This involves the development of pure conventional high explosives. In addition, experiments and tests will be carried out to develop and test the non-nuclear components of the nuclear weapon.

There is some disagreement between international lawyers as to when a Party to the NPT breaks the Treaty. Some argue that the NPT is only broken once a nuclear weapon (a device capable of releasing nuclear energy in an uncontrolled manner) has been assembled.[27] Others insist that if there were facts indicating that the purpose of a particular activity was the acquisition of a nuclear explosive device, it would tend to show non-compliance.[28]

Whatever the criteria, when a country embarks on stage four (development engineering), it can be reasonably assumed that it intends to produce nuclear weapons. The resources entailed and the momentum generated by gearing up to stage four indicates a political commitment to building, rather than exploring, a nuclear weapons capability.

2.2 Uncertainty could hasten a military attack

"For some, the absence of reliable intelligence supports the case for the military option"

Like other regional powers with available resources and technology, such as Egypt and Saudi Arabia, it is plausible that Iran has completed stages one, two and three. As yet, there is no firm evidence to suggest that Iran has proceeded to development engineering (stage four) in any serious way. Reportedly, Iran has acquired an implosion-design for a nuclear weapon from A. Q. Khan (the 'father' of Pakistan's nuclear weapons) but, given the open literature available, it would have little difficulty in designing a nuclear weapon itself if it wanted to.[29]

Taking into account the developments Iran has made in its civil nuclear programme, it is likely that Iran has the technical capability to complete stages four and five without much difficulty. Crucially, it could not reach stage six until it produced a significant amount of fissile material – about four or five kg of plutonium or about 20 or 25 kg of HEU. This explains the international political focus on Iran's enrichment capability.

As described in section one, Iran could acquire the fissile material for nuclear weapons using one of two methods: By chemically removing (separating or reprocessing) plutonium or by using HEU produced in its gas centrifuge plant at Natanz.

Making predictions about the dates at which specific nuclear facilities will come into operation, and further estimating how long it would take Iran to produce enough fissile material, is a difficult business. And the absence of hard evidence, to prove or disprove suspicions that Iran is building a nuclear weapons programme or indeed to certify how far it has progressed with its civil nuclear programme, affects political thinking in different ways. For some, the absence of reliable intelligence supports the case for the military option.[30]

It is known that Iran has made less progress than predicted in its uranium enrichment activities, installing and operating less gas centrifuges than expected.[31] It is not yet operating the first 164-centrifuge cascade at Natanz consistently, producing smaller amounts of low enriched uranium than expected. Despite opening a second cascade (again of 164 centrifuges) at Natanz in October 2006, Iran has not installed as many centrifuge cascades in the Natanz pilot plant as anticipated. In April 2006, IAEA officials expected that, by August 2006, Iran would have installed five cascades at the PFEP, each containing 164 centrifuges.

Still, there are a number of estimates about how long it could take Iran to develop a nuclear weapons capability. The US Director of National Intelligence, John D. Negroponte, told the US Senate Committee on 2 February 2006 that Iran "will likely have the capability to produce a nuclear weapon within the next decade".[32] In April 2006, he told *Time* magazine: "Iran is five years away from having a nuclear weapon."[33]

David Albright, President of the Washington-based Institute for Science and International Security (ISIS) and an authoritative expert on Iran's nuclear programme, writing in the *Bulletin of the Atomic Scientists*, estimates that "Iran is not likely to have enough highly-enriched uranium until 2009".[34] According to this rational, taking into account the time needed to convert the HEU into nuclear weapon components, Iran would not have nuclear weapons until 2010 or later.

It must be emphasised that all estimates are very uncertain. Many details about Iran's technical nuclear capabilities are not known. American officials tend to overstate Iran's capabilities, often for political reasons, arguing the need to 'play it safe'. By comparison, history shows that it usually takes significantly longer to produce nuclear weapons than estimates suggest, a scientific optimism that dates back to the Manhattan Project. There are very good reasons to question those who argue that action is needed before time runs out.

3 Possible impact of pre-emptive military strikes

Even according to the most conservative assessments, Iran is some years away from having enough fissile material to fabricate its first nuclear weapon. Nevertheless, some within the American and Israeli administrations believe that, if Iran is to be prevented from obtaining a nuclear weapons capability, military action must be taken before it begins to produce fissile material. In practice, this would mean making a pre-emptive air strikes on those facilities that enable or are related to the production of fissile material.

3.1 Possible Targets

As far as the nuclear facilities are concerned, at a minimum the Americans would have to attack:

- The Kalaye Electric Company in Tehran that produces components for gas centrifuges and the Teheran Nuclear Research Centre;
- The heavy-water reactor under construction and the heavy-water production plant at Arak;
- The uranium-enrichment facilities at Natanz;
- The uranium-mines and mills at Saghand;
- The research reactors and the UCF at Isfahan; and possibly
- The nuclear-power reactor at Bushehr.

Contemplation of an attack on Bushehr presents a dilemma. If an attack were made after the nuclear reactor became operational, the scale of nuclear contamination could be catastrophic. If it were made before, the risk of harming Russians working at the reactor could result in a serious diplomatic dispute. Yet, if a military strike was designed to remove Iran's routes to enrichment, Bushehr could not be ignored. It is unlikely that the Russians or the IAEA could provide adequate guarantees to convince the US that, in the aftermath of a military strike, facilities at Bushehr could not be diverted, especially if Iran withdrew from the NPT.

It is outside the scope of this report to assess the particularities of a military strike but, merely taking into account the nature and number of targets involved, it is unlikely that it would be a short, limited engagement.

3.2 Pre-emptive strikes might fail

The following factors cast doubt as to whether pre-emptive military air strikes could succeed:

- Large number of targets
- Well protected and hidden facilities
- Inadequate intelligence
- Likely survival of technicians and scientists

"Each nuclear site contains many targets so that a large number, perhaps many hundreds, of aircraft sorties would be required."

Each nuclear site contains many targets so that a large number, perhaps many hundreds, of aircraft sorties would be required if all the sites were to be targeted. There is an inherent contradiction in arguments that a military strike could both encompass all key nuclear facilities and be surgical and brief. Furthermore, many of these targets are in built-up, heavily populated areas, increasring significantly the risk of collateral damage and civilian casualties.

It is known that some of the Iranian nuclear facilities are underground. Over the past few years, Iran's Natanz uranium enrichment facility has been buried under more than fifteen metres of reinforced concrete and soil. According to Colonel Sam Gardiner: "There is evidence that similar hardening is taking place at other facilities, and there is some evidence of facilities being placed inside populated areas."[35]

Added to this, there is a real possibility that Iran has constructed secret facilities in anticipation of a military strike. It is also conceivable that Iran has built false targets; installations that appear to hold nuclear facilities but in fact act as decoys. With inadequate intelligence, it is unlikely that it would be possible to identify and subsequently destroy the number of targets needed to set back Iran's nuclear programme significantly.

Finally, unless Iran's scientific and technological know-how was eliminated, it would only be a matter of time before technicians reconstructed its nuclear programme. It is anticipated that many key personnel could survive military strikes. And, as Section Four demonstrates, there would be options open to Iran to rebuild nuclear facilities in a relatively short period of time.

The wars in Iraq and Afghanistan are overstretching American military forces and it is highly unlikely that any military attack on Iran would involve a ground invasion. Given the convincing case that air strikes alone could not destroy Iran's nuclear capability, it is possible that a military strike on Iran would be counter-productive. They may fail to achieve the stated aim of significantly setting back Iran's nuclear programme, and instead harden the Iranian commitment to building a bomb in the shortest possible time.

4 Building a nuclear weapon in the aftermath of a military attack

"With regard to Iran, there is no reason to believe that an attack on the facilities in Bushehr, Arak, or Natanz would have any different consequence than the Osirak example. Such an attack would likely embolden and enhance Iran's nuclear prospects in the long term. In the absence of an Iranian nuclear weapon program, which IAEA inspectors have yet to find, a preemptive attack by the United States or Israel would provide Iran with the impetus and justification to pursue a full blown covert nuclear deterrent program, without the inconvenience of IAEA inspections. The most troubling aspect of such a scenario is that, unlike Iraq in 1981, Iran is not dependent on foreign imports for nuclear technology and already has available the raw materials, and most of the designs and techniques, required to pursue a nuclear weapons program. Iran has the necessary know-how and has already produced every stage of the nuclear fuel cycle."

Sammy Salama and Karen Ruster, "A Preemptive Attack on Iran's Nuclear Facilities: Possible Consequences". *Centre for Non-proliferation Studies*, 12 August 2004.[36]

4.1 Recovery time

It has been estimated by some that military strikes could set back Iran's nuclear programme by two or three years or, optimistically, destroy it altogether.[37] There are several reasons to dispute this.

As discussed above, a military attack on Iran's nuclear facilities could kill a number of nuclear scientists and engineers, and may be designed partly to do just that, but it is very unlikely to destroy Iran's nuclear knowledge base completely. In time, surviving scientists would be able to repair damage done to nuclear facilities, or rebuild them completely, and resume the nuclear programme.

Furthermore, it is to be expected that the Iranian population, including the scientific community, would unite around the current government and support any subsequent moves to attain a nuclear weapon for deterrent purposes. If Iran stood by threats to withdraw from the NPT, putting an end to IAEA inspections, there would be little prospect of international or domestic containment. Added to this, Iran is in the strong position of having the raw materials needed to resume a nuclear weapons programme.

It is conceivable that, if the Iranian regime took the political decision to change the nature of its nuclear programme and embark on a crash nuclear programme, i.e. committing itself fully to building a nuclear weapon in the aftermath of an attack – using all available assets, including damaged nuclear equipment and materials, and purchasing additional supplies on the black-market – it could achieve this in less than two or three years.

It should be clarified that this would be a crash military programme – to secure a nuclear weapon by any means – incomparable to the industrial scale nuclear programme that Iran is developing at present.

As stated previously, most estimates predict that if Iran continues along the current trajectory, it will take at least five years to build a bomb. If so, pre-emptive strikes far from buying a significant amount of additional time might actually speed up Iran's progress towards obtaining a nuclear weapon and, in turn, shut down diplomatic possibilities for the future.

4.2 Rebuilding

In the unlikely event that all Iran's known nuclear facilities were destroyed in a military attack, it could re-establish a nuclear weapons programme:

- Using stored, fresh nuclear fuel to produce HEU in a small centrifuge facility to fabricate a nuclear weapon; or
- If either the Bushehr or Arak reactors were operational at the time of an attack, chemically removing plutonium from any irradiated reactor fuel elements that survive the strike and using it to fabricate a nuclear weapon (as detailed in Section One, a smaller quantity of plutonium compared to HEU is needed to construct a nuclear weapon).

This process could be hastened if:

- Iran has a stock of uranium hexafluoride concealed at a secret facility, it would then be possible to produce HEU in a relatively short time and resume its nuclear programme;
- Iran has secretly constructed a small primitive reactor, fuelled with natural uranium, to produce plutonium for nuclear weapons; or
- Iran purchased fissile material from the nuclear black market.

The US Congressional House Select Committee on Intelligence Policy admitted that the US intelligence agencies have inadequate intelligence on Iranian nuclear facilities; increasing the likelihood that, if Iran has constructed secret facilities, they will remain undiscovered, even after a military strike.

Iran has threatened to withdraw from the NPT if it is attacked. Article X of the NPT states that:

> *"Each Party shall in exercising its national sovereignty have the right to withdraw from the Treaty if it decides that extraordinary events, related to the subject matter of this Treaty, have jeopardized the supreme interests of its country. It shall give notice of such withdrawal to all other Parties to the Treaty and to the United Nations Security Council three months in advance. Such notice shall include a statement of the extraordinary events it regards as having jeopardized its supreme interests".*

If Iran were to withdraw from the NPT, its safeguards agreement with the IAEA would then no longer be in force. With no more inspections of nuclear facilities by IAEA inspectors, the international community would have no knowledge of, or control over, Iran's nuclear activities. If it decided to do so, Iran could then pursue a nuclear-weapon programme without any international monitoring.

4.3 The relevance of Bushehr

The fresh nuclear fuel at the Bushehr reactor would be a considerable help to Iran if it chose to start or re-establish a nuclear weapons programme after a military attack. This fuel will contain uranium enriched to about 3.5%in uranium-235. As described in an authoritative report by the *Nonproliferation Policy Education Centre*, if the fuel pellets of fresh light-water reactor fuel are used, the needed capacity for a gas centrifuge plant to produce HEU for use in nuclear weapons would be reduced "by a factor of five". The report points out that low-enriched uranium reactor fuel "is about 80% of the way to HEU. It takes comparatively little additional 'separative work' to upgrade low-enriched uranium to HEU."

"With the option of military action still on the table, Iran has presumably made preparations to protect its nuclear programme "

This means that Iran could use the low-enriched uranium fresh fuel, supplied for the Bushehr reactor, to produce HEU for use in nuclear weapons. Iran would need a relatively small number of centrifuges to do this and it is conceivable that, if stowed in secure storage, a small number could survive a military attack.

The operators of a nuclear-power reactor normally refuel the reactor in three fuel cycles; about one third of the fuel is replaced with fresh fuel about every 18 months. The *Nonproliferation Policy Education Centre* explains that "about a year after a light-water reactor of the size Iran has brought on line, as much as 60 Nagasaki bombs' worth of near-weapons grade material (i.e. plutonium) could be seized and the first bomb made in a matter of weeks."

We know that Iran has had experience in plutonium chemistry. It could separate the plutonium from the seized fuel elements. The effectiveness and reliability of a nuclear weapon made from this reactor-grade plutonium would be similar to that of nuclear weapons made from weapon-grade plutonium.[39]

The plutonium in fuel elements that had been irradiated for longer periods could be separated from the elements in a similar way. It is extremely unlikely that all the fresh and irradiated fuel elements would be destroyed completely in an air attack. The same arguments apply to the heavy-water research reactor at Arak, but this is not expected to be operational until several years after Bushehr.[40]

4.4 A nuclear crash programme

It is possible to make general estimates of how long it would take Iran to start producing fissile material for nuclear weapons in the aftermath of a military strike. With the option of military action still on the table, Iran has presumably made preparations to protect its nuclear programme from attack and to enable it to resume operations as quickly as possible.

The time taken to do this would depend on:

- Whether Iran is building a clandestine facility to enrich uranium and, if so, what stage they are at and how rapidly it can be finished;
- What stocks of uranium hexafluoride Iran has and what amount of the material can be accumulated;
- Whether Iran has a stock of gas centrifuges or components for centrifuges and how soon centrifuges could be put into operation; and
- If the Bushehr reactor is operating, whether Iran has built a clandestine chemical plant to remove plutonium from irradiated fuel elements.

The argument that military strikes would set back Iran's nuclear facilities by two or three years is based on the following assumptions:

- A military strike would disable the key components of Iran's nuclear programme
- Without these key components Iran would be without the means to build a nuclear weapon

"A military attack would not destroy all the irradiated fuel elements completely. Some could be salvaged."

This argument can be questioned by reference to the following plausible scenarios:

(1) *Clandestine facilities* Given Iran's stated plans in 2006 to install 3000 centrifuges at Natanz, it can be reasonably assumed that Iran has component parts for many more centrifuges than are operating currently. A clandestine Iranian enrichment facility, prepared in advance, containing say, 6,000 P-1 centrifuges could produce about 20 kg of highly enriched uranium in three months, enough for a nuclear weapon. If P-2 centrifuges were available, the time could be reduced to about six weeks. The larger the number of centrifuges used, the shorter the time taken to produce sufficiently highly enriched uranium.

Obviously, the time required to get a clandestine enrichment operation up to speed would depend upon the extent of prior preparations. Under clandestine conditions and unlike the current programme, Iran could seek outside technical and material support to overcome difficulties. The extent to which a decision to accelerate a clandestine programme would change the nature of Iran's nuclear programme should not be underestimated. People forget that the Manhatten Project produced a nuclear weapon in four years from a much lower level of scientific and technical understanding.

(2) *Bushehr* If the Bushehr nuclear-power reactor were operating, there would be enough plutonium in four spent fuel assemblies to produce a nuclear weapon. In the event of a military strike on Bushehr, Russian oversight would be lifted. The Iranians could remove the plutonium from these assemblies in a small chemical facility built for the purpose. This could be done relatively quickly – within a few weeks.

A military attack would not destroy all the irradiated fuel elements completely. Some could be salvaged. However, it must be emphasised once again that to bomb the Bushehr reactor after it has started operating would have catastrophic consequences; it would create a second Chernobyl that would contaminate the region and far beyond.

(3) Furthermore, Iran could acquire weapon-usable nuclear material (plutonium or HEU) illicitly on the nuclear black-market. Because the amount of fissile material needed for each nuclear weapon is small (the size of an orange, in the case of plutonium) it would not be difficult to smuggle it into Iran. Iran may also be able to acquire weapon-usable fissile material from another country.

Therefore, it is possible that a military attack on the Iranian nuclear programme would not delay it by a significant time period if, as expected, the Iranians anticipated a military attack, made preparations for a rapid recovery and, after it, withdrew from the NPT and undertook a post-attack crash programme to acquire nuclear weapons.In fact, if Iran devoted maximum effort and resources to building a nuclear weapon post military strikes, it could achieve this in less than two years.

Conclusion

If Iran is moving towards a nuclear weapons capability at present, it is doing so relatively slowly. In theory, military attacks on the centrifuge plant at Natanz and the Bushehr reactor could set back progress towards this goal. However, this assumes that Iran will continue to work at a similar pace post- as pre-military action.

In the aftermath of a military strike, and if Iran devoted maximum effort and resources to building one nuclear bomb, it could achieve this in a relatively short amount of time: less than the two years muted as the time military strikes would set back its current programme. The argument that military strikes would buy needed time is flawed. It does not take into account the time already available to pursue diplomacy; it inflates the likelihood of military success and underplays the possibility of hardened Iranian determination leading to a nuclear crash programme. Post military attacks, it is possible that Iran would be able to build a nuclear weapon and would then wield one in an environment of incalculably greater hostility.

In the long-term, Iran cannot be deterred from attaining a nuclear weapons capability by bombing its facilities, and presumably continuing to do so if Iran reconstitutes its programme.

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APPENDIX I

Uranium enrichment

In every thousand atoms of naturally occurring uranium there are only 7 atoms of uranium-235; the other 993 are atoms of uranium-238. This concentration of uranium-235 is too low to produce the super-critical mass needed to generate a fission chain reaction in a nuclear weapon. Therefore, the concentration of uranium-235 in uranium is increased in a process called enrichment.

The extent of the enrichment depends on the purpose for which the uranium is required. Some military reactors used to produce plutonium for use in nuclear weapons are fuelled with natural uranium and use no enriched uranium. Commercial nuclear-power reactors use uranium enriched to about 4% in uranium-235. For use in a fission nuclear weapon, uranium is enriched to more than 90%.

Uranium-235 and uranium-238 are chemically identical and so it is necessary to use a physical method to separate and enrich them. The difference between the two isotopes is that the nucleus of a uranium-238 atom contains three more neutrons than the nucleus of a uranium-235 atom, giving a minute difference in the weight of the atoms. This difference can be used to separate (enrich) the isotopes in gas centrifuges.

For the enrichment of uranium, gas centrifuges use a uranium gas – uranium hexafluoride – that is a solid at room temperature. This is converted into a gas by heating it to a temperature of about 64°c.

Pure uranium hexafluoride is obtained by converting yellowcake in a chemical plant called a conversion plant. The conversion plant produces pure uranium hexafluoride.

The gas centrifuge method of enriching uranium uses a rapidly spinning centrifuge to separate the uranium-235 atoms from uranium-238 atoms. The centrifuge consists of a cylindrical drum that rotates at very high speeds.

The heavier uranium-238 concentrates at the outer radius of the drum and is made to flow in one direction. The uranium-235 is enriched near the central axis of the drum and is made to flow in the opposite direction. The enriched uranium-235 is collected through an exit orifice.

The separation of the uranium isotopes at each stage in a centrifuge plant is very small. Therefore, a centrifuge plant contains a very large number of centrifuges, constructed in a cascade to achieve a useful output of enriched uranium. The slightly enriched uranium-235 from the first centrifuge in the cascade is fed into the input nozzle of the next centrifuge, the slightly more enriched uranium-235 from the second centrifuge, is fed into the third centrifuge and so on. Arranging the very large number of centrifuges and the flow of uranium hexafluoride gas through them is a complex process.

The requirements for the materials used in the construction of gas centrifuges are very demanding. In particular, the outer casing of the drum and the rotor bearings must be made from a material with a high tensile strength. A centrifuge plant can be built up in stages, step by step, as demand for enriched uranium dictates.

APPENDIX II

The use of plutonium produced in a civil nuclear-power reactor to fabricate nuclear weapons

In a civil nuclear reactor, generating electricity, plutonium is inevitably produced. Reactor-grade plutonium (R-Pu) will generally consist of 60% of the isotope plutonium-239, 24% plutonium-240, 9% plutonium-241 and 1% plutonium-238. Plutonium produced in plutonium-production reactors – used to produce plutonium specifically for nuclear weapons (W-Pu) – will generally consist of at least 93% of plutonium-239 and less than 7% plutonium-240.

Eminent and highly competent physicists, with extensive knowledge of the characteristics and production of nuclear weapons such as Richard L. Garwin,[41] Theodore Taylor, J. Carson Mark, Harold M. Agnew, Wolfgang K. H. Panofsky and Michael M. May have stated that effective nuclear weapons can be fabricated from reactor-grade plutonium.

Carson Mark, the head of the Theoretical Division at the Los Alamos National Laboratory for many years, stated: "The difficulties of developing an effective design of the most straightforward type are not appreciably greater with reactor-grade plutonium than those that have to be met for the use of weapons-grade plutonium".[42]

The US Department of Energy has also warned about the weapon-usability of R-Pu,[43] as did Hans Blix when he was Director General of the International Atomic Energy Agency.[44]

In fact, as Matthew Bunn of Harvard University explained at an International Atomic Energy Agency conference in Vienna in June 1997, it may actually be easier for a terrorist group or a small country to make a nuclear weapon from R-Pu than from W-Pu because no neutron generator would be required to initiate the explosion.[45] A neutron from spontaneous fission of Plutonium-240 would initiate it instead.

A major difference between reactor-grade and weapon-grade plutonium is that the critical mass (the minimum amount needed to sustain a fission chain reaction and produce a nuclear explosion) of a bare sphere of R-Pu is thirteen kilograms compared with ten kilograms for W-Pu (both for alpha-phase metal with a density of 19.6 grams per cubic centimetre). This means that about 30% more R-Pu is needed than W-Pu to fabricate a nuclear weapon.

Iran's experiments with plutonium

If plutonium is produced in the heavy water reactor planned at Arak and used to produce nuclear weapons, it will be necessary to chemically separate the plutonium from the irradiated reactor fuel elements. Similarly, if Iran decided to use plutonium produced in the Bushehr nuclear-power reactor in nuclear weapons, it would need to separate the plutonium from the unused uranium and fission products in the fuel elements. Therefore, the experiments performed by the Iranians in plutonium separation are significant.

The Iranian government acknowledged to the IAEA that it irradiated uranium dioxide targets with neutrons in the Tehran Research Reactor and subsequently chemically separated the plutonium produced in the targets. According to the Iranians, only a small amount of plutonium was separated.

Removing plutonium from spent reactor fuel elements (known as reprocessing) is straightforward chemistry. The elements are very radioactive and adequate shielding against radiation is required. The PUREX (an acronym standing for plutonium and uranium recovery by extraction) process is the standard chemical method for reprocessing. Unused uranium, plutonium, and fission products are separated from each other and from the fission products.

The spent (irradiated) fuel is first dissolved into concentrated nitric acid. An organic solvent composed of 30% tributyl phosphate (TBP) in odorless kerosene is used to recover the uranium and plutonium; the fission products remain in the aqueous nitric phase. Once separated from the fission products, further processing allows the separation of the heavier plutonium from the uranium. The PUREX extraction process uses a liquid-liquid extraction process in which a complex is formed between the tributyl phosphate and the extracted plutonium and uranium.

It is likely that Iran would use the PUREX method if it reprocessed irradiated reactor fuel elements to any significant extent.

APPENDIX III

Laser isotope separation (LIS)

Uranium can be enriched using a laser method called laser isotope separation (LIS). LIS separates uranium isotopes more efficiently than gas centrifuges because it is based on the fact that each isotope of an element has a unique set of electronic energy states. Consequently, electrons of atoms of each isotope will absorb light of a specific colour (i.e., of a specific energy level).

If illuminated by a laser beam containing light of this precise colour, electrons of atoms of the selected isotope will absorb photons and become excited. An atom may give up its excited electron, and become a positively charged ion. The atoms of the other isotopes will not absorb photons, because they do not have the “right” energy, and will not be ionised. The ionised atoms can be separated from the neutral ones by an electromagnetic field.

The Iranians have experimented with an Atomic Vapor Laser Isotope Separation (ALVIS) system that consists of two main units – a separator and a laser. When used to separate uranium isotopes, natural uranium metal is vaporised in the separator, using an intense electron beam that creates a uranium vapour stream in a vacuum chamber that rapidly moves away from the uranium metal. The vapour contains atoms of uranium-235 and uranium-238.

The laser unit uses powerful copper-vapour lasers that emit beams of green-yellow light. This light energises (excites) ‘dye’ lasers that emit beams of red-orange light of precisely the right colour (i.e., frequency) to photoionise preferentially U-235 atoms. The red-orange beams are passed through the vapour of uranium atoms.

Uranium-235 atoms absorb photons of the red-orange light whereas uranium-238 atoms do not. The excited uranium-235 atoms eject the excited electrons, becoming ionised; the uranium-238 atoms remain untouched. An electromagnetic field moves the positively charged uranium-235 atoms to a collecting plate where they condense. The enriched uranium-235 can then be removed. The remaining uranium vapour, containing a much greater proportion of uranium-238 than natural uranium, flows on through the s eparator chamber and is removed.

The ALVIS photoionisation process has an atomic selectivity of more than 10,000 – only one ion of uranium-238 is produced for every 10,000 ions of uranium-235. This high enrichment efficiency, combined with the fact that relatively little energy is needed to operate the separator and laser systems, makes the operating and capital costs of the ALVIS process relatively low. This makes laser-isotope separation attractive as a method of enrichment.

Would Air Strikes Work?

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About this report

This report provides a detailed briefing on the Iranian nuclear programme as well as a breakdown of individual facilities. It sets out the paths open to Iran should it wish to pursue a nuclear weapon capability. It argues that, alongside other regional powers such as Saudi Arabia and Egypt, it is reasonable to assume that Iran has conducted research and development into the fabrication of nuclear weapons. However, there is no evidence to suggest that Iran has embarked on production engineering – putting in place the technical facilities needed to build a bomb – and it is known that it is some way off being able to produce the amount of fissile material needed to produce a nuclear weapon.

Dr. Frank Barnaby goes on to assess whether air strikes intended to destroy Iran's nuclear weapons potential would succeed and the consequences of military action. Given the limited intelligence about the location of all of Iran's nuclear facilities, it is very unlikely that air strikes would succeed in destroying Iran's nuclear weapons potential. In the aftermath of a military strike, and if Iran devoted maximum effort and resources to a crash clandestine nuclear weapons programme, it could build a weapon in within a couple of years.

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