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Nuclear capabilities in the Middle East

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Background paper

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Abbreviations

AEA	Atomic Energy Agency
AERI	Atomic Energy Research Institute
EBW	Exploding bridgewire
FEP	Fuel Enrichment Plant
HEU	Highly enriched uranium
HLWMC	Hot Laboratory and Waste Management Centre
IAEA	International Atomic Energy Agency
ICR	inventory change report
KACST	King Abdulaziz City for Science and Technology
LEU	Low-enriched uranium
MNSR	Miniature neutron-source reactor
NRC	Nuclear Research Centre
PFEP	Pilot Fuel Enrichment Plant
SESAME	Experimental Science and Applications for the Middle East
SIR	Safeguards Implementation Report
TNRC	Tajoura Nuclear Research Centre
TNRC	Tehran Nuclear Research Centre
TRR	Tehran Research Reactor
WMD	Weapons of mass destruction

I. Introduction

This paper describes the nuclear capabilities that are understood to exist in the Middle East.[1] For most of the countries involved, these capabilities have been declared to the International Atomic Energy Agency (IAEA) as part of a civilian nuclear programme. To the extent to which nuclear facilities also can be used for non-peaceful purposes, this potential dual-use is noted. Current and past nuclear activities relating to military purposes are also described.

II. Nuclear-armed state[2]

Israel

In the Middle East, Israel is assumed to have a nuclear monopoly. Its nuclear weapons capabilities, though never officially confirmed, are generally accepted as fact throughout the world. Israel initiated a nuclear programme in the mid 1950s and crossed the weapons threshold about a decade later, the sixth nation to do so. Today, remaining outside the NPT, Israel is considered to be a de facto nuclear-weapons state with an advanced and sizeable arsenal. Since a pledge by Prime Minister Levi Eshkol in the mid 1960s that 'Israel will not be the first nation to introduce nuclear weapons to the Middle East', all his successors have adhered to the same formula, maintaining a strict policy of nuclear opacity, often called 'nuclear ambiguity'. What it meant by not being the first to 'introduce' nuclear weapons was itself unstated, but it came to mean not to be the first to declare or test the weapons.[3] Notwithstanding the secrecy about virtually every aspect of the nuclear programme, it is regarded by most Israelis as a sacred national insurance policy necessary to prevent any existential threat to the nation. Nuclear deterrence is intimately tied to the national resolve not to allow a repeat of the Holocaust.

In September 1969, Israeli Prime Minister Golda Meir reached a secret agreement with President Richard Nixon, which laid the foundations for a tacit, 'don't ask, don't tell' policy between the US and Israel on the nuclear issue. Meir reportedly explained to Nixon why Israel had been compelled to develop a nuclear capability, and why it could not sign the NPT, but also stated that Israel would not defy the treaty either.[4] Nixon agreed that the Israeli bomb would be tolerated by the US as long as Israel did not acknowledge it in public.

In the wake of the Meir–Nixon agreement, the US no longer pressured Israel to sign the NPT. Although the US maintained a pro forma policy of promoting NPT universality, it adopted a de facto policy of looking the other way when it came to Israel's invisible bomb. To this day, all Israeli and US governments have adhered to this understanding. Although Washington occasionally pushes Israel to negotiate arms-control arrangements, the US

[1] For the purposes of this paper, the Middle East region is defined as the countries of the Arab world, Israel and Iran. Some analyses of potential proliferation dynamics in the region also include Turkey in what can be called the 'greater Middle East'. A description of Turkey's nuclear capabilities can be found in International Institute for Strategic Studies, 'Turkey: power-balance concerns', Chapter Three of *Iran's Nuclear, Biological and Chemical Capabilities: A net Assessment* (IISS: London, 2011), pp. 61-72.

[2] This section includes several excerpts from 'Israel: nuclear monopoly in danger', Chapter Six of *Nuclear Programmes in the Middle East: In the shadow of Iran* (IISS: London, 2008).

[3] Cohen, A. *Israel and the Bomb* (Columbia University Press: New York, 1998), pp. 234–35.

[4] Burr, W. and Cohen, A., 'Israel Crosses the Threshold', *Bulletin of the Atomic Scientists*, vol. 62, no. 3, May/June 2006, p. 28.

adheres to 'realpolitik' on the fundamental nuclear issue and offers Israel neither nuclear assistance nor criticism.

Israel's nuclear programme dates to 1957 when France agreed to provide technical and industrial assistance to build a reactor and separation plant at Dimona in the Negev desert. The Dimona project included all the technological components required for enabling Israel to achieve a plutonium-based nuclear-weapons infrastructure within about a decade. The most important component of the Dimona project was a top-secret underground-reprocessing plant dedicated to the extraction of weapons-grade plutonium.

The reactor and reprocessing plant are at the Negev Nuclear Research Centre, which is located about nine miles southeast of the town of Dimona. The facility includes working units for a full array of nuclear-weapons-related activities, from uranium conversion, fuel fabrication, uranium enrichment, to a production reactor and reprocessing mechanisms, and possibly weapons-specific facilities. In addition to its production capabilities it is believed that the centre also serves as Israel's national laboratory in the nuclear field. The Dimona complex includes Israel's plutonium-producing reactor, which is a heavy-water-moderated, natural-uranium-fuelled research reactor originally modelled on the French EL3 reactor. It reportedly initially had a thermal output of 24MWt and was later upgraded to 40MWt and then 70MWt.

Israel also operates a nuclear research centre at Soreq, about 25 miles south of Tel Aviv. Known as MAMAG, it was built in the late 1950s around a small, light-water, pool-type, 1MWt research reactor (which subsequently expanded to 5MWt) that Israel had purchased from the USA as part of the 'Atoms for Peace' programme. The Soreq reactor is the only facility in Israel under IAEA safeguards. According to MAMAG's website, it is used for 'research and training in nuclear engineering, neutron radiography and diffraction, activation analysis and changing colours of semi-precious and precious stones'. According to some reports, another part of MAMAG serves primarily as a nuclear-weapons research and design facility.[5] No reliable information as to the division of labour between the two research centres is available.

Israel is believed to have full fuel-cycle capabilities, but details of the various components of the system such as fuel fabrication are unknown. It is assumed that some of the weaponization activity of the Israeli nuclear complex is carried out in other secret facilities.

While there is little doubt as to Israel's status as nuclear-armed, there is a great deal of uncertainty as to the true extent of Israeli nuclear capabilities. Public information on the subject of Israel's nuclear programme has not significantly changed for 25 years. Ever since Ben-Gurion told the Knesset in December 1960 that the Dimona reactor was intended for peaceful applications, no prime minister has ever given any factual statement on the nation's nuclear programme. There is no confirmed or even authoritative data available about any aspect of Israel's nuclear capabilities.

The result is that there are widely divergent estimates of both the number of warheads and the amount of fissile material Israel has produced. These estimates are based on logical assumptions about the power of the Dimona reactor, its operational procedures, Israeli weapon design and other variables, but there is no authoritative evidence to support any of these assumptions. Many of the estimates were based on the technical information provided by Vanunu to the *Sunday Times* in 1986,[6] but close scrutiny of the information he provided

[5] Hough, H., 'Israel's Nuclear Infrastructure', *Jane's Intelligence Review*, Nov. 1994, p. 508.

[6] 'Revealed: The Secrets of Israel's Nuclear Arsenals', *Sunday Times*, 5 Oct. 1986.

indicates both inconsistencies and knowledge gaps. These inconsistencies (especially relating to the power of the Dimona reactor and its production rate) can probably be attributed to Vanunu's limited understanding of the larger picture at the Dimona facility, its working practices and its history. If so, all historical extrapolations based on Vanunu's disclosures are intrinsically problematic.

David Albright, of the US-based Institute for Science and International Security, calculated that Israel could have produced around 510–650kg of weapons-grade plutonium by the end of 2003, depending on assumptions of the size of and working procedures at the Dimona reactor.[7] Initially, the *Sunday Times* made the claim that Vanunu's data about Israeli plutonium production at Dimona indicated that Israel might have as many as 200 bombs. In his subsequent book, *The Invisible Bomb*, British physicist Frank Barnaby, the scientist who had interviewed Vanunu for the *Sunday Times*, was more cautious. Allowing for wider margins of uncertainty, he estimated that Israel 'produced enough plutonium to construct between 100 to 200 nuclear weapons'. He also estimated, based on Vanunu's reporting of the production of Lithium-6 at Dimona, that 'Israel may have about 35 thermonuclear weapons'.[8]

These uncertainties are compounded when it comes to estimating the size of Israel's nuclear arsenal because further assumptions about weapon design and efficiency need to be factored in. Indeed, estimates range from as few as 60 weapons to as many as 400.[9] Until Vanunu's testimony in 1986, Israel's nuclear arsenal had generally been estimated to be in the area of two or three dozen weapons.

III. States that have posed proliferation concerns

Iran[10]

Iran's nuclear effort is designed to support an independent nuclear-power programme. The Bushehr nuclear power plant, which reached criticality in March, is scheduled to begin producing electricity in August. But the still secretive nature of other aspects of Iran's nuclear programme, its economic inefficiency and inconsistencies, and the substantial evidence that has emerged of weapons-related activities raise doubts about claims that the purpose is solely peaceful. The evidence leads to an analytical conclusion that the programme is also intended to give Iran a nuclear-weapons capability.

[7] Albright, D., 'ISIS Estimates of Unirradiated Fissile Material in De Facto Nuclear Weapon States, Produced in Nuclear Weapons Programs', Institute for Science and International Security, revised June 2005. Albright acknowledges that his calculations are based on somewhat arbitrary speculations on the reactor size and its mode of operation. 'The plutonium estimate is based on the Dimona reactor having a power of about 40MWt initially that increased to about 70MWt in the mid-1970s. Although significantly higher reactor powers are discussed publicly, the underlying reactor-based rationale for the higher reactor powers has proven hard to confirm or recreate'.

[8] Barnaby, F., *The Invisible Bomb* (I.B.Tauris: London, 1989), p. 24.

[9] In 1999, the US Defense Intelligence Agency (DIA) assessed that Israel had 60–80 nuclear weapons. See excerpt from DIA report reproduced in Rowan Scarborough, *Rumsfeld's War: The Untold Story of America's Anti-Terrorist Commander* (Regnery Publishing: Washington DC, 2004), pp. 194–223. The DIA may simply have used the 60–80 plutonium weapons estimate calculated by Anthony Cordesman in Cordesman, *Perilous Prospects: The Peace Process and the Arab–Israeli Military Balance* (Boulder, CO: Westview Press, 1996), p. 234. Over 400 is the exaggerated estimate of Kenneth S. Brower. See Brower, 'A Propensity for Conflict: Potential Scenarios and Outcomes of War in the Middle East', *Jane's Intelligence Review*, Special Report no. 14, February 1997, pp. 14–15. The Stockholm International Peace Research Institute estimates 100–200 warheads. See *SIPRI Yearbook 2007: Armaments, Disarmament and International Security* (SIPRI: Stockholm, 2007), p. 548.

[10] This section draws from the IISS Strategic Dossier on *Iran's Nuclear, Biological and Chemical Capabilities: A net Assessment, op cit.*

Iran acquired basic nuclear-research facilities at the Tehran Nuclear Research Centre (TNRC) from the USA in the 1960s, and developed a cadre of top nuclear scientists. Following the 1974 oil crisis, the Shah launched an ambitious programme to develop nuclear power and fuel-cycle facilities for enrichment and reprocessing. This had the dual purpose of achieving energy independence (while conserving Iran's oil and gas resources) and creating a nuclear-weapons option to suit Iran's emergence as a dominant power in the Gulf. The 1979 Iranian revolution devastated the Shah's nuclear programme: top scientists fled the country, Western suppliers withdrew earlier offers of nuclear assistance, and Supreme Leader Ayatollah Ruhollah Khomeini, opposed the development of nuclear technology.

Following the death of Ayatollah Khomeini in 1989, Iran embarked on an effort to expand both its overt civilian programme and its undeclared nuclear experiments in conversion, reprocessing and enrichment. In the mid-1990s, Russia started work to complete the Bushehr nuclear power reactor, and Iran obtained technical assistance from Russian institutes and individuals to assist its indigenous efforts to design and build uranium mining and milling facilities, heavy-water production plants and heavy-water research reactors. Pressure from Washington blocked other assistance, such as construction of a centrifuge plant and pilot laser-enrichment facility. Similarly, Washington persuaded China to end nuclear cooperation with Iran in 1997, but not before Iran received technical assistance in uranium mining, laser enrichment, research reactors and (most importantly) construction of an industrial-scale uranium-conversion facility. Finally, with the benefit of additional centrifuge assistance in the mid-1990s from the black-market network led by Pakistani metallurgist Abdul Qadeer Khan, Iran was able to begin the construction in 2001 of pilot and industrial-scale enrichment facilities near the city of Natanz. All told, undeclared nuclear activities and violations of Iran's safeguards agreement with the IAEA proceeded for nearly 20 years—from imports of uranium and acquisition of centrifuge technology, to experiments with conversion, uranium-metal production and reprocessing.[11]

At the front end of Iran's fuel cycle, mining and milling facilities operate at Gchine and have been developed at Saghand to produce natural uranium in the form of yellowcake. In the next stage of the nuclear-fuel cycle, yellowcake is converted to uranium hexafluoride (UF_6) at the Uranium Conversion Facility at Esfahan. This gasified uranium is then transported to Natanz for enrichment of the uranium-235 (U-235) component at the underground Fuel Enrichment Plant (FEP).

Iran began enrichment at Natanz in small quantities in 2006, provoking a UN Security Council resolution demanding its suspension, which Iran has defied. As of May 2011, cascades comprising 5,860 centrifuges were being used to enrich uranium. Another 3,000 centrifuges are installed but not being used for enrichment. The stated purpose of Natanz, which has the capacity to hold about 50,000 centrifuges, is to produce low-enriched uranium (LEU) to fuel light-water power reactors. But Russia has promised to supply fuel for the lifetime of Bushehr, and no other power reactor is likely to be built in Iran for many years.[12] Alternatively, if reconfigured—and if Iran did not care about international reactions—the

[11] IAEA, 'Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran', GOV/3003/75, 10 Nov. 2003, para 48.

[12] Iran's current justification for LEU production is that it will be needed to fuel a 360MWe reactor that is said to be in the design phase at Darkhovin. Iran's inability to procure or produce a pressure vessel that meets safety standards will almost surely delay the project indefinitely.

centrifuges operating there now could be used to produce highly enriched uranium (HEU)[13] for one nuclear weapon each year.

At the above-ground Pilot Fuel Enrichment Plant (PFEP) at Natanz, two cascades were set up in 2010 to enrich uranium to 19.75% for the stated purpose of producing fuel for Iran's largest research reactor, the Tehran Research Reactor (TRR). Iran presently lacks the ability to produce this fuel and has no operating reactor where it can test and certify its safety. The increased enrichment has sparked concern because, with time and accumulation, it would bring Iran closer to being able to produce weapons-usable HEU.

The PFEP has also been used for development of more-advanced centrifuges, which may be able to produce enriched uranium about four times more efficiently than the first-generation models employed at the FEP. Second-generation models are to be installed at the underground Fordow Fuel Enrichment Plant, which was revealed in September 2009. Iran's announcement in December 2009 that it intends to build a total of 10 other enrichment plants, while surely an exaggeration, added to international unease. Iran claims it needs to provide advance notification of design plans as required by its standard safeguards agreement.

Iran has four small research reactors at Esfahan, which are too small to produce substantial quantities of plutonium. But there have been safeguards failures at its largest operational research reactor, the TRR in Tehran, and the country is constructing a 40MWt heavy-water research reactor (IR-40) near Arak. When completed, this could produce enough plutonium for military uses, if Iran develops a reprocessing capability. Similarly sized reactors ostensibly built for research have been employed by India, Pakistan and North Korea to produce plutonium for weapons.[14] Natural uranium fuel for the IR-40 is to be fabricated at a Fuel Manufacturing Plant at Esfahan, where a single fuel assembly has been produced. Iran has announced that it has no plans to reprocess spent fuel and in 2005 said that it will commit to refraining from building reprocessing facilities if its enrichment programme is accepted.[15]

Western intelligence agencies have shared large amounts of information with the IAEA that they believe came out of a covert Iranian nuclear-weapons programme. If true, the information provides snapshots of a sophisticated weapons programme whose goal is to produce a uranium implosion device. In its May 2011 report, the Agency listed seven particular areas of concern about undisclosed activities of a 'possible military dimension' for which it had yet to receive satisfactory clarification and 'which may have continued beyond 2004', including experiments with nuclear bomb triggers, and missile re-entry vehicle redesign activities for a new payload assessed as being nuclear in nature. [16]

The IAEA has stressed that the documents concerning possible military dimensions come from multiple sources and through its own efforts and contain a great deal of internal consistency.[17] The agency noted in 2008 that it had no information—apart from a document on uranium metal conversion and casting—on the actual design or manufacture by Iran of

[13] LEU is defined as containing less than 20% U-235; HEU is defined as above 20% U-235.

[14] India's CIRUS reactor, which produced the plutonium for its first nuclear explosion, was 40MWt. Pakistan's two plutonium-producing reactors at Khushab are rated at 40MWt and 50MWt. North Korea's reactor at Youngbyon is estimated to be 25MWt.

[15] Zarif, J., 'An Unnecessary Crisis: Setting the Record Straight about Iran's Nuclear Program', advertisement published in the *New York Times*, 18 November 2005.

[16] IAEA, 'Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions in the Islamic Republic of Iran', GOV/2011/29, 24 May 2011, para 35.

[17] IAEA, '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', GOV/2010/10, 18 February 2011, para 41.

nuclear material components of a nuclear weapon.[18] Iran insists that the allegations of weapons studies are baseless and that the documents in question are forgeries. Iran further contends that it has satisfactorily answered all questions posed by the IAEA in a 2007 Work Plan and that the IAEA has not provided it with any official and authenticated documents regarding the alleged studies.[19]

Iraq[20]

In the 1970s and 1980s, Saddam Hussein launched a nuclear weapons programme that came perilously close to fruition before the facilities were destroyed in the 1991 attack by a US-led coalition. Ten major nuclear installations and many other factories and state-owned establishments were used to support the weapons programme. Today, very little of the pre-1991 nuclear infrastructure remains. After the 1991 war, Saddam Hussein had maintained a personal desire to reconstitute weapons of mass destruction (WMD) programmes, but UN sanctions crippled his ability to do so.[21] In April 2003, in the immediate aftermath of the second Iraq war, the main nuclear facility at Tuwaitha was looted and barrels containing yellowcake were stolen. A subsequent IAEA report noted that the missing material posed no proliferation concern although efforts were required to recover the dispersed material. Current Iraqi activities in the nuclear field are mostly related to agriculture or health.

Libya

After developing both civilian and military nuclear programmes for some three decades, the Libyan regime of Colonel Muammar Gadhafi announced in December 2003 that it was giving up its pursuit of nuclear weapons, as well as other non-conventional capabilities. It subsequently allowed the USA and UK to dismantle and remove nuclear facilities and components connected to its weapons programme, including uranium-conversion and enrichment equipment, and cooperated faithfully with IAEA inspectors, winning commendation from the United Nations Security Council. Libya also agreed to return 20kg of HEU stored at its Tajoura Nuclear Research Centre (TNRC) to Russia and, with the help of the USA, to convert the 10MWt research reactor there to run on LEU fuel to minimise the proliferation risk. Libya continues to maintain a workforce of nuclear scientists and technicians and is receiving foreign assistance in order to move closer towards its long-held ambitions to develop a nuclear-powered desalination capability.

The TNRC was at the heart of Libya's declared nuclear programme prior to December 2003, and it has remained so since then, albeit with a name change following its merger with two other national research organizations in late 2003. The IRT-1 10MWt pool-type research reactor is designed for isotope production, as well as basic and applied nuclear research.

The reactor building for the IRT-1 also houses a 100W critical assembly used for basic experiments and to train operators. In addition, the TNRC is home to various supporting

[18] IAEA, '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', GOV/2008/59, 19 November 2008, p.14.

[19] IAEA, 'Communication dated 1 March 2010 received from the Permanent Mission of the Islamic Republic of Iran to the Agency regarding the implementation of safeguards in Iran', INFCIRC/786, 2 Mar. 2010.

[20] This and subsequent sections include several excerpts from the IISS Strategic Dossier: *Nuclear Programmes in the Middle East: In the shadow of Iran*.

[21] Iraq Survey Group, *Comprehensive Report of the Special Advisor to the DCI on Iraq's WMD* ['Duelfer Report'] (Central Intelligence Agency: Washinton DC, 30 Sep. 2004), vol. 1.

facilities including a neutron-generator complex and laboratories that focus on physics research, neutron physics, radiation biophysics, material research, mass spectrometry and activation analysis. The centre's Russian-built TM4-A Tokamak fusion reactor is designed for plasma physics and fusion studies. There is also a radiochemical laboratory with hot cells for medical radioisotope production. This laboratory was also used for undeclared plutonium separation experiments.

Libya imported 2,263 tonnes of yellowcake (uranium oxide concentrate, U_3O_8) from Niger between 1978 and 1981.

Undeclared programme[22]

During the 1980s and first half of the 1990s, Tajoura appears to have been the main locus of undeclared activities, which included early work on gas-centrifuge enrichment, plutonium separation and uranium conversion. It appears that Libya initially considered producing plutonium as a means of fulfilling weapons ambitions. Between 1984 and 1990, several dozen small uranium oxide and uranium metal targets were produced and irradiated in the IRT-1 reactor, and from which very small amounts of plutonium were then separated. The extraction took place using hot cells located in the radiochemical laboratory at the TNRC. Beyond these separation experiments, however, Libya did not progress any further in terms of producing plutonium for weapons purposes. The small size of the IRT-1 meant that plutonium could only have been produced in small quantities.

During the second half of the 1990s, once Libya had enlisted the support of the Pakistan-based A.Q. Khan proliferation network, the undeclared programme focused specifically on uranium enrichment using gas centrifuges. The renewed focus on enrichment occurred at locations other than the TNRC in an apparent attempt to hide the undeclared activity from the IAEA. Through the Khan network, Tripoli received gas centrifuges, UF_6, nuclear-weapon designs, hi-tech machine tools (precision lathes, flow-formers), speciality metals (maraging steel, high-strength aluminium) and nuclear-related training for some of its personnel outside of Libya.

It should be noted that, although the network significantly accelerated Libya's progress in the nuclear field, Tripoli had failed to produce any enriched uranium let alone weapons-grade material by December 2003. There was insufficient domestic expertise in important fields such as mechanical engineering related to centrifuge development, owing to Libya's under-developed scientific and industrial infrastructure. Also of importance was the network's chequered record as a supplier: some equipment and components were delivered in a damaged condition, and some Libyan requests were not fulfilled at all. For example, only 1.7 tonnes of UF6 were delivered out of the 20 tonnes ordered; rotors and other key components were missing from the additional 10,000 L-2 (Libya, second generation) centrifuges that were ordered; some parts for the L-2 machines were damaged; the two complete L-2 centrifuges were not in an operable state; and some of the key drawings related to weapon design were not included.

Of particular proliferation concern was the A.Q. Khan network's provision to Libya, at the end of 2001 and in early 2002, of design and fabrication documentation related to nuclear

[22] This section draws upon three reports by the Director General, IAEA, *Implementation of the NPT Safeguards Agreement of the Socialist People's Libyan Arab Jamahiriya,* GOV/2004/12, GOV/2004/33 and GOV/2004/59, dated 20 February 2004, 28 May 2004 and 30 August 2004, respectively; as well as Wyn Bowen, *Libya and Nuclear Proliferation: Stepping back from the brink*, IISS Adelphi Paper 380 (Taylor & Francis for the IISS: Abingdon, May 2006).

weapons. The specifications related to a 10KT implosion device based on a Chinese design from the late 1960s and weighing approximately 500kg with a diameter of less than a meter, which had originally been supplied to Pakistan for aircraft or missile delivery. The documentation encompassed the process for casting uranium metal into a bomb core and manufacturing explosive lenses for compressing the core to generate a chain reaction.[23] The Libyans claimed that they did not examine the documentation to determine its usefulness. Indeed, during inspections in 2004, IAEA inspectors did not identify any facilities in Libya that had dealt with the actual weapons components specifically, nor did they find any indications of work related to nuclear weapons development.

After Libya announced in December 2003 that it would give up its nuclear-weapons ambitions, the American and British governments worked jointly to dismantle the clandestine programme and to remove sensitive equipment and materials from the country. Libya also sent to Russia 16kg of HEU fuel for the IRT-1 for blending down into LEU.

In a final report in 2008 on its Libya investigation, the IAEA concluded:

> As corrective measures, Libya has made all declared nuclear material available for Agency verification, submitted relevant inventory change reports (ICRs), and provided relevant design information. The Agency has been able to verify the non-diversion of declared nuclear material in Libya.
>
> Given the fact that Libya's programme extended over two decades and was conducted to a great extent clandestinely, and in view of the corresponding lack of supporting documentation, there are some parts of Libya's past programme which the Agency has not been able to reconstruct fully. However, with the cooperation and transparent response shown by Libya, the Agency has been able to conclude that Libya's statements concerning its nuclear programme are not inconsistent with the Agency's findings.[24]

Syria

Israel's 6 September 2007 bombing of a facility at Dair Alzour near the town of al-Kibar on the Euphrates River in northeastern Syria stopped what appears to have been the initial stage of a nuclear-weapons programme. A 24 May 2011 report by the IAEA Director General concludes that 'the destroyed building was very likely a nuclear reactor.[25] The IAEA based this assessment on the features of the destroyed building; the configuration of the infrastructure at the site prior to the bombing, including its connections for cooling and treated water; analysis of samples from the site, including anthropogenic uranium; and the incompatibility of the features of the Dair Alzour site with Syria's stated claim that its purpose was missile related.

The US Government in April 2008 released information demonstrating that the facility was a gas-cooled graphite-moderated reactor capable of producing plutonium for nuclear weapons. Undated photographs taken from inside the reactor, apparently by Israeli intelligence agents, showed the heat-control rods from the top of the reactor and other features similar to the North Korean 5MWe reactor at Yongbyon. Photographs taken after the

[23] Broad, W. and Sanger, D., 'Pakistan's Black Market May Sell Nuclear Secrets, *New York Times*, 21 Mar. 2005; Director General, IAEA, *Implementation of the NPT Safeguards Agreement of the Socialist People's Libyan Arab Jamahiriya*, GOV/2004/33, 28 May 2004, p. 7.

[24] Director General, IAEA, Implementation of the NPT Safeguards Agreement of the Socialist People's Libyan Arab Jamahiriya, GOV/2008/39, 12 September 2008, pp. 6-7.

[25] IAEA, 'Implementation of the NPT Safeguards Agreement in the Syrian Arab Republic', GOV/2011/30, 24 May, para 24.

bombing also showed the contours of a concrete reactor vessel, shielded heat-exchange rooms and a probable spent fuel pond. The reactor was destroyed before it had begun operations or been fuelled. It was not configured to produce electricity, and appeared to be ill suited for research.

According to the US briefing, information spanning a decade indicated sustained nuclear cooperation between Syria and North Korea, although analysts were uncertain of the purpose until 2007. The briefing said that:

- Senior North Korean officials from Yongbyon made multiple visits to Syria before construction of the reactor began in 2001.
- In 2002, North Korean officials were procuring equipment for an undisclosed site in Syria. North Korea that same year sought a gas-cooled reactor component that the US believed was intended for the Syrian site.
- A North Korean nuclear organization and Syrian officials involved in the covert nuclear programme reportedly were involved in a cargo transfer from North Korea to what the US assessed was 'probably' Dair Alzour in 2006.
- North Korean nuclear officials were located 'in the region' both early and late in 2007. North Korean advisers also 'probably assisted with damage assessment' after the reactor was destroyed.
- A high-level North Korean delegation travelled to Syria shortly after the reactor was destroyed and met with officials associated with Syria's covert nuclear programme.

According to the US briefing, construction of the Dair Alzour facility began in 2001. US intelligence analysts who had looked carefully at the site over the years had been unsure whether it posed a nuclear threat.[26] If it did have the same capacity as Yongbyon, the Dair Alzour reactor would have been capable of producing approximately 6 kilogrammes of plutonium per year, roughly enough for one weapon. Before it could be weaponised, however, the irradiated reactor fuel would first require a cooling period of over a year, after which the plutonium would need to be separated in a specialised reprocessing facility. The Dair Alzour site lacked such a facility. Nor was there evidence that Syria had obtained natural uranium fresh fuel for the reactor.[27]

Syrian efforts to conceal the reactor, both before and after the bombing, lend support to the assessment that it had a non-peaceful purpose. During construction, Syria added a roof and thin walls to alter the building outline, which otherwise resembled that of the Yongbyon reactor. An earthen wall was built to block the view of the reactor from the bottom of the canyon in which it was situated.

Syria destroyed the bombed facility in October 2007 and covered the remains with earth. Syria then erected a new metal-framed building over the site, making it difficult for any future inspections to excavate any remaining reactor debris. Syria also began preparing a pipeline to connect the site's water-pumping station to a water-treatment plant a few kilometres away, apparently to cover up the original purpose of the Dair Alzour site.

Civilian nuclear research

The bulk of Syria's civilian nuclear-related work consists of several facilities at the Der Al-Hadjar Nuclear Research Centre near Damascus. In 1991, China began constructing a SRR-1

[26] Broad, W. and Mazzetti, M., 'Yet Another Photo of Site in Syria, Yet More Questions', *New York Times*, 27 Oct. 2007.
[27] Wright, R., 'N. Koreans Taped at Syrian Reactor', *Washington Post*, 24 April 2008.

30KWt miniature neutron-source reactor (MNSR) under an IAEA technical assistance project. The reactor went critical in March 1996. This small reactor is primarily used for teaching students, training staff and conducting neutron-activation analysis but today barely functions. A reactor of this type cannot produce fissile material. To fuel the reactor, China supplied 980.4g of U-235 enriched to 90.2%. The reactor came with two hot cells, with 5cm-thick lead windows, but Syria said it has never used them to produce isotopes.

In 2008 and 2009, particles of anthropogenic uranium of a type not previously reported were found at the MNSR. After amending earlier statements, Syria explained in 2010 that the particles originated from previously unreported preparation of small amounts of uranyl nitrate using yellowcake. The yellowcake, which had been reported to the Agency, was the by-product of operations of a pilot plant at Homs for the purification of phosphoric acid to reduce the uranium content of fertiliser. Inconsistencies in Syria's initial responses were finally clarified in April 2011.[28]

It has been widely reported that the Khan network offered nuclear technology and hardware to Syria,[29] but there is no reliable information that such a transfer ever took place. In December 2007, Syrian President Bashar al-Assad said his government had rejected an offer from Khan in 2001. Khan visited Syria in late 1997 and 1998, officially at the invitation of the Ministry of Higher Education to give lectures on nuclear materials. According to unconfirmed press reports, beginning in 2001, Khan and three associates from his Pakistan laboratory who were consulting with officials involved in Syria's nuclear programme held their meetings in Iran in order to keep the meetings from being exposed.[30]

IV. States with significant civilian nuclear infrastructure

Algeria

Algeria has one of the most advanced nuclear-science programmes in the Arab world. The programme includes four now-safeguarded nuclear facilities at two different sites. The Nur research reactor (DZ-0001; 'Nur' means 'light' in Arabic) is located at the Draria nuclear complex, about 20km east of Algiers. Supplied by Argentina, the 1MWt pool-type light-water reactor went critical in 1989 and is used for research and the production of isotopes. It uses 19.75% enriched uranium fuel, also provided by Argentina. A pilot fuel-fabrication plant, named UDEC, is also located at the Draria nuclear complex. Initiated under a 1985 agreement, the project was not completed until 2000 because of domestic security conditions.

The Es Salam research reactor (DZ-0002; 'Es Salam' means 'peace' in Arabic) is located in Ain Oussera, in the Sahara desert, 140km south of Algiers. Supplied by China, the reactor went critical in 1992. It is a 15MWt heavy-water-moderated reactor. Beijing stated in 1991 that it had also delivered to Algeria 11 metric tonnes of heavy water and 216 fuel modules, totalling 909kg of 3% LEU.[31] The Ain Oussera site also hosts various facilities, including an isotope-production plant, hot-cell laboratories and waste-storage tanks. These are collectively

[28] IAEA, GOV/2011/30, *op cit*, paras 27-32.

[29] CIA, 'Unclassified Report to Congress on the Acquisition of Technology Relating to Weapons of Mass Destruction and Advanced Conventional Munitions, 1 January–31 December 2004', p. 5.

[30] Frantz, D., 'Black Market Nuclear Probe Focuses On Syria', *Los Angeles Times*, 24 June 2004.

[31] Burr, W., 'The Algerian Nuclear Problem, 1991: Controversy over the Es Salam Nuclear Reactor', National Security Archive, Electronic Briefing Book no. 228, 10 Sep. 2007.

mentioned in the IAEA list of safeguarded installations as 'AURES-1', although it is not clear whether every facility at the site is safeguarded.

Finally, Algeria has significant nuclear-research activity, based around two poles: the Centre des Sciences et de la Technologie Nucléaire, created in 1976; and four regional centres, based respectively in Draria, Algiers, Birine and Tamanrasset. The country also has significant uranium deposits—some 56,000 tonnes—in the southeast part of the country in a region known as the Targui Shield near Tamanrasset. It also has considerable amounts of phosphate ore from which uranium could be recovered.

Proliferation concerns

Concerns about Algeria's nuclear intentions surfaced in early 1991 as US satellite observations revealed the existence and nature of the Ain Oussera project. This gave rise to proliferation concerns on several grounds. The Es Salam complex is of a type that would potentially allow for the production of weapons-grade plutonium; satellite observation of the site raised many questions. The size of the cooling towers was said to exceed the requirements of a 15MWt reactor and be consistent instead with a 25 or even 60MWt reactor.[32] Adding to grounds for suspicion, the site was well protected, including by Soviet-made SA-5 surface-to-air missiles.

Algeria announced in April 1991 that the Es Salam reactor's purpose was the production of isotopes and electricity generation. Such a reactor could also be used to produce plutonium for a weapons programme. Estimates regarding the quantity of plutonium that could be generated by the reactor at 15 MWt vary around 3–5kg a year. However, in June 1995 it was reported—in line with US intelligence estimates at the time—that the reactor was in fact fuelled with 3% LEU instead of natural uranium, thus decreasing the quantity of plutonium that it was able to produce annually, which was evaluated at 1kg, assuming a power of 15 MWt.[33]

Satellite imagery dated 2000 showed a new, heavy-walled building, in a fenced area separated from the main site, which was described by independent experts as a possible candidate for a plutonium reprocessing facility. According to various reports, Algeria was unwilling to open the Ain Oussera hot-cells facility to inspections, and removed two fuel rods from the reactor without reporting it to the IAEA.[34] However, the US is said to be satisfied with IAEA monitoring of the Ain Oussera complex.[35] To the extent that Algeria has any reprocessing capabilities today, the facilities are apparently dormant.

[32] Hibbs, M., 'Cooling towers are key to claim Algeria is building bomb reactor', *Nucleonics Week,* 18 April 1991, pp. 7–8; MacLachlan, A., 'Algerian leader asserts good faith in nuclear research reactor plans', *Nucleonics Week*, 23 May 1991, pp. 11–12; US intelligence assessed that the reactor's power could be increased to 50MWt. See the collection of declassified US documents available at: http://www.gwu.edu/~nsarchiv/nukevault/ebb228/index.htm. Some analysts pointed out that China had a history of building research reactors with 'disproportionate cooling'. See Albright, D. and Hinderstein, C., 'Algeria: Big Deal in the Desert?' *Bulletin of the Atomic Scientists,* vol. 57, no. 3, 1 May 2001, p. 47.

[33] Wisconsin Project on Arms Control, 'Algeria: Nuclear Reactor Update', p. 12; US intelligence noted in 1991 that a power increase to 50MWt would imply a capability to produce 3kg of plutonium annually.

[34] Albright and Hinderstein (note 35), p. 49.

[35] Cirincione, J., *Deadly Arsenals: Nuclear, Biological, and Chemical Threats,* 2nd edn (Carnegie Endowment for International Peace: Washington DC, 2005), p. 301.

Egypt

Next to Israel and Iran, Egypt has one of the most advanced nuclear programmes in the region. It has a well-established administrative infrastructure and multiple nuclear facilities spread over several locations, including two research reactors and exploratory uranium-mining operations. Yet although it is capable of producing plutonium from irradiated reactor fuel, Egypt is far from possessing an independent capability in the most sensitive areas of the fuel cycle.

Egypt's Atomic Energy Agency (AEA) is organised into four research centres. Two of these are located at Inshas: the Nuclear Research Centre (NRC) and the Hot Laboratory and Waste Management Centre (HLWMC). Nasr City is the site of the other two: the National Centre for Radiation Research and Technology and the National Centre for Nuclear Safety and Radiation Control.

The NRC facilities at Inshas include two research reactors, a fuel-manufacturing pilot plant and a pilot-scale conversion plant, all of which are under IAEA safeguards. The NRC also houses an accelerator, a heavy-water laboratory and a cyclotron. Sold by Russia in 1991, the cyclotron offers a universal source of charged particles and a source of fast neutrons from a beryllium target, and is used for training in nuclear physics.

The first reactor, ETRR-1, was built in 1958 and went critical in 1961. It has been used for solid-state, nuclear and reactor physics, chemical research, isotope production and biological irradiation. The 10% enriched uranium fuel for the reactor was imported from Russia. Since the initial load, the reactor is not known to have been refuelled.

The ETRR-2 is a pool-type light-water reactor with a 22MWt capacity that was inaugurated in February 1998. The initial 19.75% enriched uranium fuel load came from Russia, and the last shipment was delivered by Argentina in 1997. Since 1998 Egypt has fabricated the fuel rods for the ETRR-2 at its indigenous fuel-fabrication plant at Inshas. This research reactor is primarily used for radioisotope production, medical and nuclear solid-state research, nuclear-engineering experiments, material-fuel tests, and various other fields to train scientists and technical personnel. It has been assessed that the ETRR-2 could produce over 6kg of plutonium a year.[36]

The HLWMC facilities include a low- and intermediate-level liquid-waste station, a radioisotope production laboratory and a radioactive-waste-disposal site. The purpose of the centre is to develop expertise in the treatment of radioactive waste and radioisotope production for medical and industrial applications. The HLWMC also includes hot cells for plutonium-extraction research. These hot cells, which do not house nuclear material requiring safeguarding under standard IAEA safeguards, are the only known facility in Egypt that, in theory, could be used to separate weapons-useable plutonium from irradiated reactor fuel.

Reporting failures

A February 2005 IAEA report identified a number of failures by Egypt to report activities as required by its safeguards agreement. The IAEA began investigating after seeing several scientific reports in 2004 published by serving and former AEA officials, which indicated the existence of past undeclared nuclear activities. Egypt was reported to have produced 'several kilograms of uranium metal and of uranium tetrafluoride—a precursor to uranium

[36] Bowen, W. and Kidd, J., 'The Nuclear Capabilities and Ambitions of Iran's Neighbors', in Henry Sokolski and Patrick Clawson, eds, *Getting Ready for a Nuclear-Ready Iran* (Strategic Studies Institute: Carlisle, PA, Oct. 2005), p. 64.

hexafluoride gas'.[37] While the experiments occurred mainly in the 1980s and 1990s, there were indications that some experiments were carried out as recently as 2003.[38]

As the details emerged, it was confirmed that between 1990 and 2003 16 experiments had been performed involving the irradiation of small amounts of natural uranium. Similar experiments had been carried out between 1982 and 1988, and before the safeguards agreement came into force. The hydrometallurgy pilot plant, which Egypt said it never completed, was intended to separate small amounts of plutonium. The IAEA also questioned Egypt's explanation as to how traces of nuclear material came to be found in environmental samples taken from Egyptian hot cells. Some of these nuclear activities occurred between 15 and 40 years ago. The projects themselves were not illegal, but the failure to make the declarations raised concerns about Egypt's intentions, the actual extent of its nuclear capabilities and whether Egypt carried out any other undeclared nuclear activity in sensitive fuel-cycle areas.

During the IAEA investigations, Egypt maintained its innocence and reaffirmed its continued commitment to its NPT obligations. It refuted allegations of a secret military programme and declared that the reporting failures were unintentional, asserting that its interpretation of its safeguards obligations differed from that of the IAEA. Cairo emphasised that its nuclear activities were meant solely for peaceful purposes and fully cooperated with the investigation. Ultimately, the IAEA found no inconsistencies between Cairo's explanations of its activities and its investigation. Given that the Egyptian nuclear programme did not extend to the extraction of plutonium or enrichment of uranium, and in light of the IAEA's final reckoning of the reporting failures, it could be concluded that Egypt's infractions were not indicative of a systematic intent to create a latent weapons capability.

Additional undeclared nuclear material in Egypt was found after the 2005 report. In 2009 the IAEA annual Safeguards Implementation Report (SIR) for 2008 reported that HEU and LEU particles had been found in environmental samples taken at Inshas Nuclear Center in 2007–2008. The Agency had not yet identified the source of the uranium particles and noted that Egypt believed they 'could have been brought into the country through contaminated radioisotope transport containers'. The HEU and LEU particles were not related to the previous set of reporting failures. By 2008 the IAEA considered those previous issues to be 'no longer outstanding', although the SIR did not explain why the Agency could make this conclusion.[39]

V. States with little or no nuclear infrastructure

Jordan

Jordan has ambitious plans to introduce nuclear power for electricity generation and water desalination, for which it has undertaken feasibility studies and sought foreign cooperation. Jordan's aspirations are connected with its uranium ore resources; the nation's 79,000 tonnes account for 2% of the world's total uranium ore reserves. In addition, Amman estimates that

[37] Jahn, G., 'Diplomats say Egyptian scientists produced nuclear material that could be used in weapons program', *Associated Press*, 4 Jan. 2005.

[38] IAEA, *Implementation of the NPT Safeguards Agreement in the Arab Republic of Egypt*, GOV/2005/9, 14 Feb. 2005.

[39] Goldschmidt, P., 'The IAEA Reports on Egypt: Reluctantly?' 19 June 2009, Carnegie Endowment for International Peace, Proliferation Analysis, 2 June 2009.

domestic phosphate deposits contain another 100,000 tonnes of uranium, which it hopes to be able to extract.[40]

With IAEA assistance, Jordan has developed a small nuclear infrastructure centred on research and uranium extraction. Jordan is the host of the Synchrotron-Light for Experimental Science and Applications for the Middle East (SESAME) initiative, a seminal IAEA/UNESCO project aimed at bolstering regional cooperation in nuclear applications. Participants include Israel, the Palestinian Authority, Bahrain, Egypt, Iran, Turkey and the United Arab Emirates. Begun in 2003, and slated to be completed in 2015, SESAME will culminate in the construction of a very large particle accelerator that generates x-ray and ultraviolet light beams, intended for use in research in medicine, physics and other fields.

Morocco

In the 1990s, Morocco began the construction of a 2MWt TRIGA Mark II-type light-water reactor, a turnkey installation supplied by General Atomics. It went critical in 2006 and was declared operational in May 2007. It is used for research and the production of isotopes, and is also intended to pave the way for a power-generation programme to meet Morocco's growing energy demand. The nation has undertaken a feasibility study for introducing nuclear power and has begun to develop the legislative and regulatory framework.

Saudi Arabia

In recent years, Saudi Arabia's interest in nuclear applications had been largely limited to applied nuclear research for industrial, agricultural and medical purposes, and radiation monitoring. Saudi Arabia has acquired accelerators and a cyclotron capable of producing isotopes. Saudi Arabia's national nuclear authority is the King Abdulaziz City for Science and Technology (KACST), established in Riyadh in 1977. In 1988 the Atomic Energy Research Institute (AERI) was established within the KACST to promote industrial applications of radiation and radioactive isotopes, nuclear power and reactors, nuclear materials, and radiation protection. Several laboratories conduct nuclear-science research under AERI's supervision. Four of the laboratories (for physical separation, chemical separation, radiochemistry, and radioactive isotopes and chemical separation) might be suitable for small-scale reprocessing, though not in quantities that would present a proliferation risk. In June 2011, Saudi Arabia announced an elaborate plan to introduce nuclear power, projecting that it will spend $300 billion on 16 nuclear reactors by 2030, with the first to be built by 2021.

Some observers believe that Saudi Arabia's provision of financial aid to Pakistan during the 1980s acted as cover for funding the Pakistani nuclear project.[41] After the US imposed sanctions in response to Pakistan's nuclear tests, Saudi Arabia apparently set up a special account to provide Pakistan with oil at a reduced price.[42] In May 1999, Saudi Defence Minister Prince Sultan allegedly visited nuclear and missile facilities at Kahuta in Pakistan. A.Q. Khan visited Saudi Arabia in November 1999, further raising suspicions, although there is no confirmation that he attempted to supply the kingdom with nuclear technology.

[40] 'Report: Jordan Says it has Uranium for Nuclear Program', Associated Press, 5 May 2007.

[41] Schiff, Z., 'Weapons of Mass Destruction and the Middle East: The View from Israel' (James A. Baker III, Institute for Public Policy, Rice University), Mar. 2003, p. 11.

[42] Kammerer, P., 'Nuclear Deterrent Deal Fuelled by Oil; Pakistan and Saudi Arabia's Agreement is Mutually Beneficial, Experts Believe', *South China Morning Post*, 3 Nov. 2003.

Others: Bahrain, Kuwait, Lebanon, Oman, Qatar, Tunisia, United Arab Emirates and Yemen

The states in the Arab world that possess no developed nuclear infrastructure include Bahrain, Kuwait, Lebanon, Oman, Qatar, Tunisia, United Arab Emirates and Yemen. Most of them, have engaged in several technical-cooperation projects with the IAEA, with a particular focus on nuclear medicine and radiation protection. Several have also expressed an interest in nuclear power. In late 2006, the six-member Gulf Cooperation Council announced that it would undertake a study for a collective nuclear-energy programme, but little has come of this study yet.

Among the national plans, only the UAE has moved forward. In December 2009, Abu Dhabi contracted with a South Korean consortium to construct four nuclear power reactors which are scheduled to be in operation by 2020. Up to 2,300 staff will be required to operate the plants, of whom 60% or more are supposed to be UAE citizens eventually. In the meantime, the UAE nuclear programme will depend heavily on foreign expertise.[43]

[43] International Institute for Strategic Studies, 'UAE leads Gulf nuclear-power plans', Strategic Comments, Feb. 2010.