IPFM
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ON FISSILE MATERIALS

Fissile Material Controls in the Middle East

Steps toward a Middle East Zone Free of Nuclear Weapons and all other Weapons of Mass Destruction

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About the IPFM

The International Panel on Fissile Materials (IPFM) was founded in January 2006. It is an independent group of arms-control and nonproliferation experts from eighteen countries, including both nuclear weapon and non-nuclear weapon states.

The mission of the IPFM is to analyze the technical basis for practical and achievable policy initiatives to secure, consolidate, and reduce stockpiles of highly enriched uranium and plutonium. These fissile materials are the key ingredients in nuclear weapons, and their control is critical to nuclear disarmament, halting the proliferation of nuclear weapons, and ensuring that terrorists do not acquire nuclear weapons.

Both military and civilian stocks of fissile materials have to be addressed. The nuclear weapon states still have enough fissile materials in their weapon and naval fuel stockpiles for tens of thousands of nuclear weapons. On the civilian side, enough plutonium has been separated to make a similarly large number of weapons. Highly enriched uranium is used in civilian reactor fuel in more than one hundred locations. The total amount used for this purpose is sufficient to make hundreds of Hiroshima-type bombs, a design potentially within the capabilities of terrorist groups.

The Panel is co-chaired by Professor R. Rajaraman of Jawaharlal Nehru University, New Delhi and Professor Frank von Hippel of Princeton University. Its 29 members include nuclear experts from Brazil, Canada, China, France, Germany, India, Iran, Japan, South Korea, Mexico, the Netherlands, Norway, Pakistan, Russia, South Africa, Sweden, the United Kingdom, and the United States. Short biographies of the panel members can be found on the IPFM website, www.fissilematerials.org.

IPFM research and reports are shared with international organizations, national governments and nongovernmental groups. The reports are available on the IPFM website and through the IPFM blog, www.fissilematerials.org/blog.

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Summary

We suggest possible initiatives for fissile material control that could serve as initial steps toward an eventual Middle East zone free of nuclear weapons and all other weapons of mass destruction. These initiatives include actions that Israel, the only regional state with nuclear weapons, could take towards nuclear disarmament; and measures of collective restraint regarding fissile material production and use to be taken by all states of the region to foster confidence that their civilian nuclear activities are indeed peaceful in intent and not being pursued as a cover to develop nuclear-weapon options.

For Israel, these initial steps include ending production of plutonium and highly enriched uranium, declaring its stockpiles of these materials, and placing increasing portions under international safeguards as steps toward their elimination. The eventual nuclear disarmament of Israel would be a necessary condition for any Middle East nuclear weapon-free zone and for a broader weapon of mass destruction free zone.

The regional measures that we propose would serve to bring a Middle East nuclear-weapon-free zone closer and make the zone more robust when it is in force. These measures include no separation of plutonium, no use of highly enriched uranium or plutonium as fuel, and no national enrichment plants. It would greatly strengthen the global nonproliferation regime if these measures were adopted worldwide, including by the nuclear weapon states.

All these measures are worth pursuing in their own rights and states should take initiatives to make progress on them wherever possible. Progress should not be held up by the imposition of linkages, time ordering or sequencing between steps.

Although we do not discuss chemical and biological weapons in this paper, it is critical that all countries in the region ratify and comply with the Chemical Weapons Convention (CWC) and Biological Weapons Convention (BWC). This has become especially important after the use of chemical weapons in the civil war in Syria in 2013 and Syria's subsequent decision to accede to the CWC, declare its stockpile and verifiably destroy its chemical weapons. Egypt and Israel should follow suit on the CWC. All three states also should ratify the BWC.

Finally, we propose that discussions be launched on the design of regional verification arrangements strong enough so that all countries in the region can have confidence in the absence of secret nuclear weapon programs. Similar verification arrangements also should be developed to increase confidence in the region that countries are complying with the Chemical and Biological Weapons Conventions.

Introduction

A Nuclear Weapon Free Zone (NWFZ) in the Middle East was first proposed in the United Nations General Assembly in 1974 by Iran and Egypt in an effort to roll back Israel's acquisition of nuclear weapons and to restrain further proliferation in the region by having all states join both a NWFZ and the nuclear Non-Proliferation Treaty (NPT).[1] The proposal drew on the model of the 1967 treaty for a Latin American nuclear weapon-free zone.[2] In 1990, the proposal was broadened by Egypt to include a ban on chemical and biological weapons, i.e., to create a Weapon of Mass Destruction (WMD)-free zone in the Middle East.[3]

The idea of nuclear weapon-free zones has proven successful. They have been established in five regions: Latin America and the Caribbean (in force since 2002), the South Pacific (1986), South-East Asia (1997), Africa (2009) and Central Asia (2009).[4] As of 2013, these zones have a combined membership of 97 states, more than half the states in the international community, and they cover the Southern hemisphere.

By contrast, the Middle East has emerged as a nuclear proliferation hotbed. Israel has held on to its nuclear weapons, refused to join the NPT, significantly expanded its stockpile of fissile material for weapons and developed advanced delivery systems. Clandestine nuclear-weapon programs were revealed in Iraq in 1991, in Libya in 2003, and in Syria in 2007 – all while these countries were parties to the NPT. In 2003, Iran was discovered to have an undeclared uranium enrichment R&D program and a reactor under construction that could potentially be used for plutonium production.

In 1995, the NPT Review and Extension Conference, which agreed to indefinitely extend the NPT, adopted a resolution calling for progress toward the creation of a Middle East WMD-free zone. The resolution "calls upon all States in the Middle East to take practical steps in appropriate forums aimed at making progress towards, inter alia, the establishment of an effectively verifiable Middle East zone free of weapons of mass destruction, nuclear, chemical and biological, and their delivery systems, and to refrain from taking any measures that preclude the achievement of this objective."[5]

Agreement on the goal of a Middle East WMD-free zone was important for securing NPT extension in 1995; in fact, without the commitment to such a zone, there would have been no extension.[6] As a result of the 1995 bargain, many NPT-states attach immense importance to the Middle East WMD-free zone and many if not all non-nuclear-weapon states believe that this part of the deal allowing for indefinite extension of the NPT has not been upheld by the nuclear-weapon states.

It was only at the 2010 NPT Review Conference, however, that it was agreed to convene a conference (by the end of 2012) on "the establishment of a Middle East zone free of nuclear weapons and all other weapons of mass destruction." Ambassador Jaakko

Laajava of Finland was appointed to serve as facilitator. In November 2012, however, the United States announced that the conference had been postponed "because of present conditions in the Middle East and the fact that states in the region have not reached agreement on acceptable conditions for a conference."[7] Agreement by all concerned parties to participate in the NPT-mandated conference would constitute an important step forward in and of itself.

Political relations in the Middle East do not appear favorable to negotiations on a WMD-free zone today but there are also grounds for possible progress towards this goal. Most Arab countries refuse to recognize Israel as long as it occupies the Palestinian territory of the West Bank and maintains the blockade of Gaza.[8] In August 2013, Palestinian representatives began U.S.-brokered peace talks with Israeli officials, the first such discussions in five years.[9]

Three countries in the region (Iraq, Libya and Syria) have acknowledged chemical weapons programs and in 2013 chemical weapons were used in Syria, the first such use since the 1980s when the Saddam Hussein regime in Iraq launched chemical weapon attacks against Iran and Iraq's own Kurdish population. In September 2013, Syria joined the Chemical Weapons Convention (CWC), declared its chemical weapons stockpile and agreed to destroy these weapons.[10] This is now mandated by a United Nations Security Council Resolution, which affirms the decision by the Organization for the Prohibition of Chemical Weapons Executive Council that Syria shall "complete the elimination of all chemical weapons material and equipment in the first half of 2014."[11]

In light of this development, Egypt, which has not signed the CWC, and Israel, which has not ratified the CWC, may be pressed to follow Syria and agree to be bound fully by the treaty. These three states may now also come under pressure to join the BWC. In the past, Egypt has refused to ratify the CWC, the Biological Weapons Convention (BWC) or the Comprehensive nuclear Test Ban Treaty (CTBT) as long as Israel refuses to join the NPT as a non-weapon state.

Finally there has been, since 2003, an on-going international confrontation over Iran's nuclear program. The prospects for resolving this dispute have increased following the June 2013 election of Hassan Rouhani as President of Iran, who said in a September 2013 address to the United Nations General Assembly that "Nuclear weapon and other weapons of mass destruction have no place in Iran's security and defense doctrine, and contradict our fundamental religious and ethical convictions."[12]

The experience of the breakthroughs that ended the Cold War and the history of the diplomatic efforts that led to the NPT, the CWC, the BWC and the CTBT suggest moreover that progress can be made in the absence of the settlement of larger political conflicts and disputes. Indeed, progress on such issues can contribute to confidence building and improved relations.

Nonproliferation status of countries in the proposed zone

For the purposes of this paper, we adopt the suggestion in the 1991 study commissioned by the U.N. Secretary General that a Middle East WMD-free zone should encompass "all States directly connected to current conflicts in the region, i.e. all States members of the League of Arab States (LAS), the Islamic Republic of Iran and Israel." [13] That definition includes all of the countries identified in Figure 1.

Israel is the only prospective member of the Middle East WMD-free zone that has nuclear weapons. A necessary condition for the zone to become a final reality therefore will be for Israel to give up its nuclear weapons and join the NPT as a non-weapon state.[14] Aside from Israel, all the countries that are potential members of a Middle East WMD-free zone are members of the NPT (Table 1).

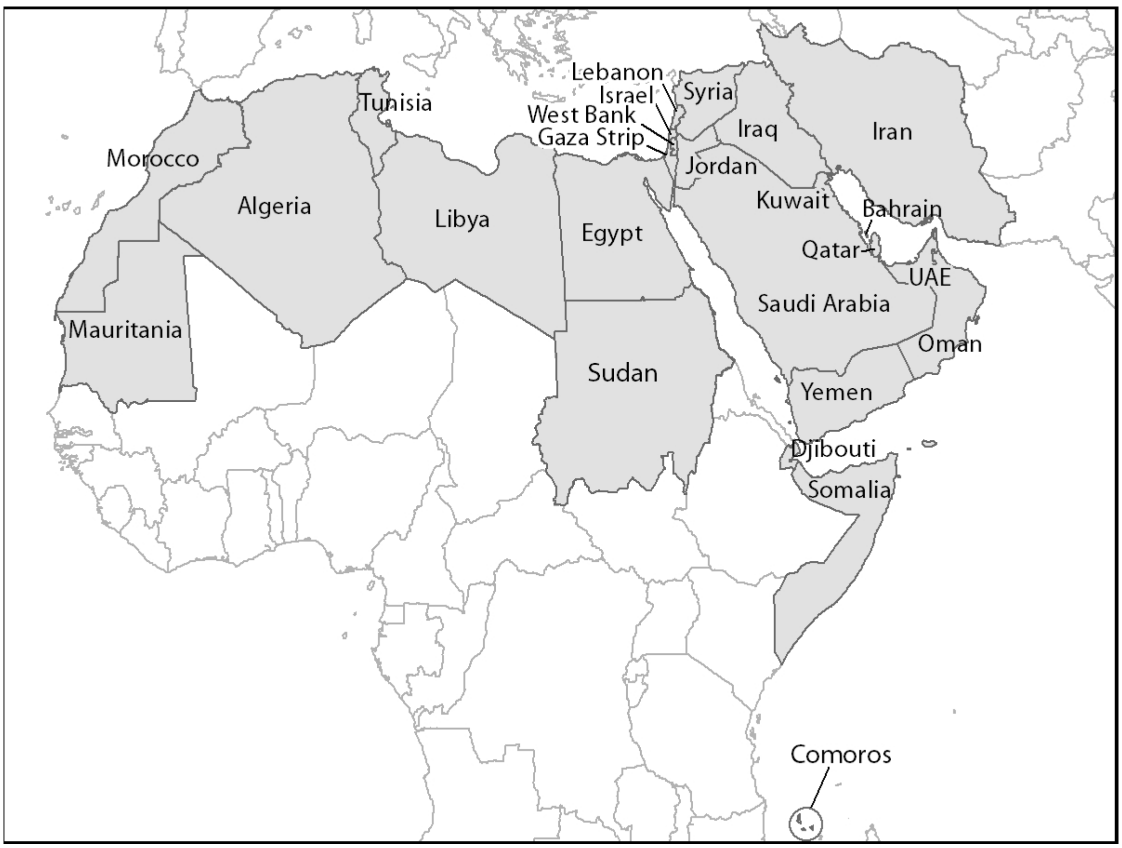

Figure 1. The labeled countries are members of the Arab League except for Iran and Israel and could be in a Middle East Nuclear Weapons Free Zone or a broader WMD-free zone. *Credit: Tsering Wangyal Shawa, Princeton University*.

All the non-weapon states in the hypothetical Middle East WMD-free zone being discussed here have signed a Comprehensive Safeguards Agreement with the International Atomic Energy Agency, except for Somalia. Djibouti has signed a safeguards agreement but, as of June 2013, it had not entered into force. These agreements require a state to declare its nuclear material and activities and enable International Atomic Energy Agency (IAEA) inspections to verify these reports.

In light of Iraq's pre-1991 clandestine efforts to acquire uranium enrichment technologies, the IAEA introduced an Additional Protocol (AP) to the Comprehensive Safeguards Agreements as a means to increase transparency of nuclear programs. As of mid-2013, only eight members of the proposed zone had signed and ratified the Additional Protocol (United Arab Emirates, Bahrain, Jordan, Kuwait, Iraq, Libya, and Mauritania). Iran signed but did not ratify the AP in 2003. It voluntarily complied with the AP until the IAEA Board of Governors transferred to the UN Security Council the issue of Iran's cooperation in resolving questions about its past nuclear activities.

The 1996 CTBT, like the NPT, is a major multilateral nuclear arms control and nonproliferation agreement that non-weapon states as well as weapon states are encouraged to join. Saudi Arabia, Syria and Somalia have not signed the CTBT, while six states in the potential Middle East WMD-free zone have signed but not yet ratified the treaty (Table 1). Since Israel, Iran and Egypt have signed, the treaty and thus shown their intent in principle to abide by its provisions, they could individually ratify or coordinate joint ratification of the CTBT as a confidence building measure.[15]

All the African members of the Arab League except Somalia have signed the African Nuclear Weapons Free Zone Treaty (the Treaty of Pelindaba), which came into force in 2012 but, as of late 2013, only three: Algeria, Libya and Mauritania, had ratified it.[16] In any case, membership in the Pelindaba Treaty, adds no constraints or verification requirements beyond those associated with non-weapon-state membership in the NPT.

The WMD-free zone under consideration is intended to cover all weapons of mass destruction, not just nuclear weapons. This would require all states in the region to ratify the CWC and BWC. Not all have done so (Table 1).

A Middle East WMD-free zone treaty would likely follow the example of current NWFZ treaties and constrain nuclear-weapon activities of outside nuclear-armed states within the region. The African NWFZ, for example, bans the stationing by other countries of "nuclear explosive devices" on the territories of the member states. The Latin American NWFZ extends a considerable distance into the contiguous seas. Most likely, members of a Middle East WMD-free zone would want to ban over-flights of their territories by nuclear-armed aircraft and also the presence of nuclear-armed ships in at least the Persian Gulf and Red Sea.

	NPT	BWC	CWC	CTBT
Algeria	12 Jan. 1995	22 July 2001	14 Aug. 1995	11 July 2003
Bahrain	3 Nov. 1988	28 Oct. 1988	28 April 1997	12 April 2004
Comoros	4 Oct. 1995	17 Sept. 2006	–	(S) 12 Dec. 1996
Djibouti	16 Oct. 1996	–	25 Jan. 2006	15 July 2005
Egypt	26 Feb. 1981	(S)10 April 1972	–	(S) 14 Oct. 1996
Iran	2 Feb. 1970	22 Aug. 1973	3 Nov. 1997	(S) 24 Sept. 1996
Iraq	29 Oct. 1969	19 June 1991	13 Jan. 2009	(S) 19 Aug. 2008
Israel	–	–	(S) 13 Jan. 1993	(S) 25 Sept. 1996
Jordan	11 Feb. 1970	30 May 1975	29 Oct. 1997	25 Aug. 1998
Kuwait	17 Nov. 1989	18 July 1972	28 May 1997	6 May 2003
Lebanon	15 July 1970	26 March 1975	20 Nov. 2008	21 Nov. 2008
Libya	26 May 1975	19 January 1982	6 Jan. 2004	6 Jan. 2004
Mauritania	26 Oct. 1993	–	9 Feb. 1998	30 April 2003
Morocco	27 Nov. 1970	21 March 2002	28 Dec. 1995	17 April 2000
Oman	23 Jan. 1997	31 March 1992	8 Feb. 1995	13 June 2003
Qatar	3 Apr. 1989	17 April 1975	3 Sept. 1997	3 March 1997
Saudi Arabia	3 Oct. 1988	24 May 1972	9 Aug. 1996	–
Somalia	5 Mar. 1970	(S) 3 July 1972	28 June 2013	–
Sudan	31 Oct. 1973	17 Oct. 2003	24 May 1999	10 June 2004
Syria	24 Sept. 1969	(S)14 April 1972	14 Sep. 2013	–
Tunisia	26 Feb. 1970	18 May 1973	15 April 1997	23 Sept. 2004
UAE	26 Sept. 1995	19 June 2008	28 Nov. 2000	18 Sept. 2000
Yemen	1 June 1979	1 June 1979	2 Oct. 2000	(S) 30 Sept. 1996

Table 1. Dates of ratification/accession [or signature (S) for states not yet parties] to the 1968 nuclear Non-Proliferation Treaty (NPT), 1972 Biological Weapons Convention (BWC), 1993 Chemical Weapons Convention (CWC), and 1996 Comprehensive Test Ban Treaty (CTBT) for possible members of a Middle East WMD-free zone.[17] In September 2013, Syria ratified the CWC.[18]

Nuclear freeze, transparency and phased reductions by Israel

To join a Middle East WMD-free zone treaty, Israel will have to give up its nuclear weapons. Israel is believed to have acquired nuclear weapons in the late 1960s.[19] Based on its estimated plutonium production, numbers of nuclear-capable delivery systems and U.S. intelligence statements, independent analysts have inferred that Israel today may have perhaps 80 warheads and that the arsenal has remained roughly constant for the past decade.[20]

Israel is believed to be the only state in the region that has produced separated plutonium, and possibly highly enriched uranium (HEU), the key ingredients in nuclear weapons. It may now have enough plutonium, including that already in weapons, for perhaps 200 nuclear warheads.

By the time a Middle East WMD-free zone came into force, Israel would need to have eliminated all of its nuclear weapons and placed all of its fissile materials under IAEA safeguards – as South Africa did when it gave up its nuclear weapons in the early 1990s. This will take time but Israel could indicate the seriousness of its willingness to do so by:

- Ending any on-going production of separated plutonium and highly enriched uranium and shutting down and/or putting under IAEA safeguards the associated production facilities; and
- Declaring its fissile material stocks and beginning to place portions under IAEA safeguards pending disposal.

These transitional steps would serve to make a Middle East WMD-free zone feasible and are discussed further below.

End plutonium and HEU production

It is widely believed that Israel's nuclear arsenal is plutonium-based and that the plutonium was produced by irradiating natural uranium fuel in a heavy-water-moderated reactor supplied by France at the Negev Nuclear Research Center near Dimona (Figure 2). It is believed that the plutonium was chemically separated from the irradiated uranium in an underground reprocessing plant adjoining the reactor.[21] By shutting down the Dimona reactor and ending reprocessing, Israel would cap the amount of plutonium that it could use to make nuclear weapons.

Most likely, these steps could be verified initially with fair confidence without access inside the site. Airborne infrared sensors should be able to verify the reactor shutdown by detecting the reduction of the temperatures of the outside of the reactor containment building and of the reactor cooling towers. The end of reprocessing in the

Figure 2. The Negev Nuclear Research Center near Dimona, Israel. The reactor under the dome at the lower right is believed to have produced plutonium for Israel's nuclear weapons, with the plutonium being separated in an adjoining underground reprocessing plant. The complex may also host a small gas-centrifuge uranium-enrichment plant. *Source: Google Earth*.

underground facility should be verifiable by off-site monitoring for the gaseous fission product, krypton-85, which is released when irradiated nuclear fuel is cut open in the first stage of reprocessing. Because the gas is chemically non-reactive, it is difficult to capture and most reprocessing plants have not bothered to try.[22]

Remote detection of the shutdown of Israel's nuclear reactor and reprocessing plant could be the first step toward regional monitoring by prospective parties to a Middle East WMD-free zone. This could also include agreements to allow mutual over-flights of unarmed instrumented aircraft or drones to detect indications of clandestine nuclear facilities.

The 1992 Open Skies Treaty between NATO and the Warsaw Pact provides a precedent for such over-flights. The Treaty allows 42 over-flights a year each over the United States and Russia/Belarus and a lesser number over other smaller countries (up to 12 per year). The sensors allowed are optical, infrared and synthetic aperture radar, but other sensors for collecting, processing and analyzing air samples could be added by consensus.[23]

There are grounds for optimism that airborne sensors could enable detection of nuclear undeclared facilities in the Middle East. The characteristic signatures of nuclear facilities include heat from a plutonium production reactor (Figure 3).It might be possible also to detect the production and use of uranium hexafluoride (UF_6), the gas used in uranium enrichment centrifuges, through its degradation product UO_2F_2 –produced by reactions with moisture in the air of UF_6 leaking from equipment in a plant that converts uranium oxide into UF_6 gas for enrichment and then back into oxide or metal form.[24] Downwind detection at a distance of krypton-85 from a reprocessing plant has been demonstrated (Figure 4).

Figure 3. The sensitivity of thermal imaging is demonstrated by the hot spots seen on the outside of rail cars carrying containers of hot glassified nuclear waste being transported from France to Germany. *Source*: *Greenpeace.*

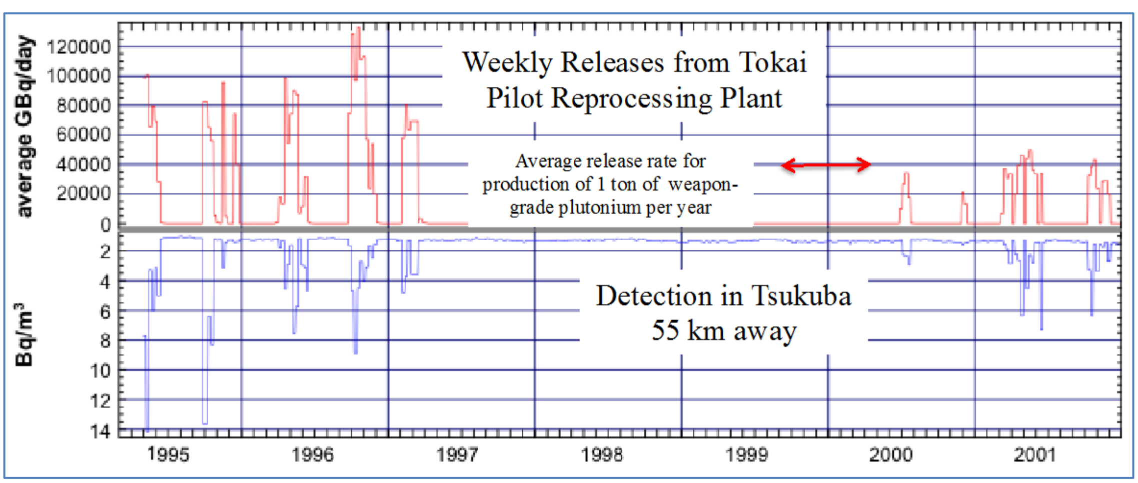

Figure 4. Remote detection of krypton-85 from Japan's Tokai reprocessing plant.[25]

Israel could decommission and dismantle its Dimona reactor after shutdown. Similarly, the adjacent reprocessing plant could be decommissioned, after the removal of high-level radioactive wastes and unreprocessed spent fuel, by filling it with concrete. The spent fuel could be placed in safeguarded storage nearby until a deep geological repository becomes available.

Alternatively, Israel could place the Dimona facilities under IAEA safeguards to assure that they are used only for peaceful purposes. There is a precedent for facility-specific IAEA safeguards in Israel. The research reactor at the Soreq Nuclear Research Center and its HEU fuel are under safeguards by agreement with the United States, which provided the reactor to Israel in the late 1950s and the fuel.

The Dimona reactor is believed to have produced not only plutonium but also tritium for some of Israel's nuclear weapons. Unlike plutonium-239, which has a half-life of 24,000 years, tritium has a half-life of about 12 years and therefore has to be replenished unless the weapons requiring it are gradually retired or are allowed to decline in yield to the order of a kiloton of chemical explosives equivalent.[26] Israel may have built up a stockpile of tritium that would allow it to maintain its weapons for a decade or more before it had to face these possibilities or could begin producing tritium from an alternative non-reactor source.[27]

Israel reportedly has conducted uranium-enrichment activities at the Negev Nuclear Research Center and possibly elsewhere as part of its nuclear-weapon program.[28] Israel should declare the sites of these activities and allow the IAEA to verify that they have ended.

Declare plutonium and HEU stocks and begin to put them under safeguards

A second step toward enabling a Middle East WMD-free zone and nuclear disarmament would be for Israel to declare the size of its stocks of separated plutonium and HEU. The estimate made for the International Panel on Fissile Materials (IPFM) is that Israel has produced 850 ±125 kg of plutonium (Figure 5).[29] Assuming 4 to 5 kg of plutonium per nuclear warhead, this would be enough for 145 to 240 warheads. Israel is believed also to have clandestinely obtained up to 300 kg of weapon-grade uranium from a U.S. naval fuel fabrication facility during the 1960s.[30]

Eventually, Israel's historical production of plutonium could be checked using techniques of "nuclear archaeology." This would include measurements of isotopic changes of certain trace elements in the permanent metal structures supporting the core of the Dimona reactor.[31] These measurements would reveal the cumulative flow or "fluence" of neutrons through the core over the lifetime of the reactor, which would provide the basis for an estimate of the total production of plutonium in the reactor.

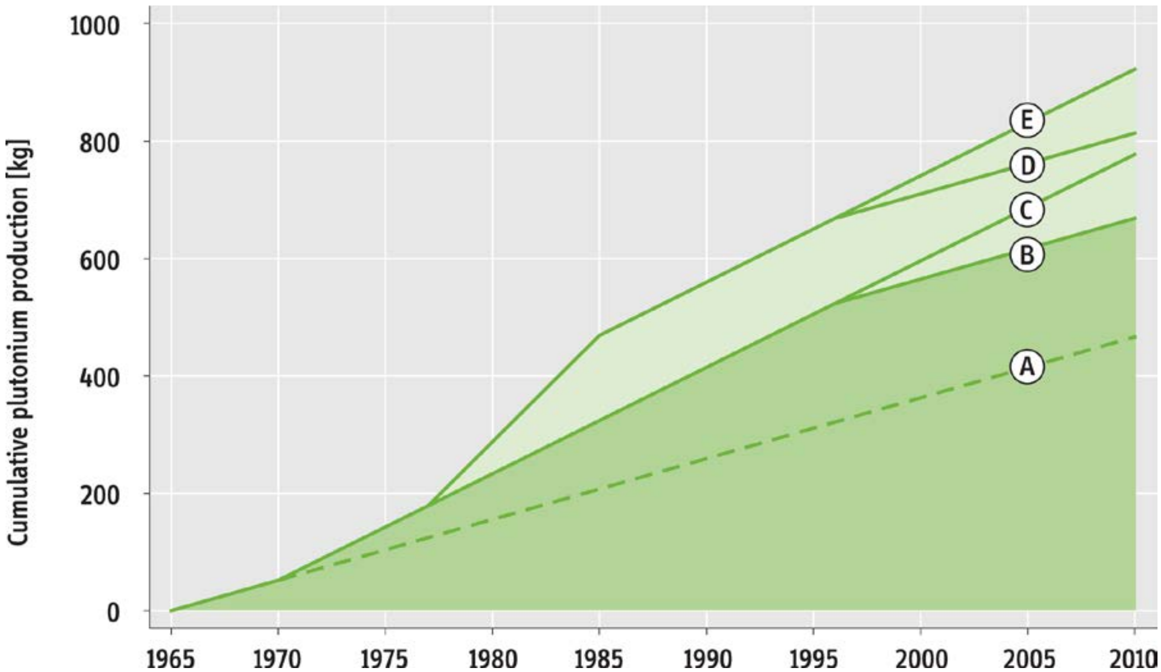

Figure 5. Estimated cumulative plutonium production in the Dimona reactor for different assumptions about its power history over almost 50 years of operation.[32]

Israel could verifiably reduce in a phased manner the quantities of plutonium and HEU that it has available for weapons by placing increasing portions of its stockpiles under international safeguards for monitored disposal.

The dismantlement of Israel's last nuclear weapons and placing of the recovered fissile material under international safeguards – in parallel with the completion of other actions by other parties to the WMD-free zone that would give Israel confidence that it no longer faced existential security threats –- would be the final step in its disarmament. By committing publicly to this goal, Israel could contribute to a regional confidence-building process and help set the basis for a verifiable Middle East WMD-free zone.

Nuclear restraint across the Middle East

Any effort to make progress towards a Middle East WMD-free zone must reckon with Israel's long standing security concerns about its neighbors, the history of covert proliferation efforts in the Middle East and the ongoing dispute over Iran's nuclear program. For Israel – and perhaps other states in the region – to participate fully in working towards such a zone will likely require significant new measures, including measures of nuclear restraint that serve as strong technical and political barriers to any future attempts to seek nuclear weapons capability. These measures would include:

- A ban on the separation and/or use of plutonium and uranium-233;
- A ban on the use of HEU as a reactor fuel;
- A limitation on uranium enrichment to less than six percent;
- An agreement, in countries that enrich, not to stockpile enriched uranium but rather to adopt a "just-in-time" system of production;
- A pause in the buildup of Iran's enrichment capacity; and
- A commitment to phase out national uranium enrichment and place any enrichment activities under multi-national control.

Below we discuss the importance and applicability to the Middle East of these proposed measures. If they were adopted globally, it would significantly strengthen the global nonproliferation regime and the foundation for a nuclear-weapon-free world.

A ban on plutonium separation and use

From a proliferation perspective, reprocessing spent uranium or thorium nuclear fuel to recover plutonium or uranium-233 respectively is intrinsically dangerous since the products are weapon-usable fissile materials.[33] Reprocessing was in fact originally developed to separate plutonium out of irradiated natural uranium for nuclear weapons. Commercial reprocessing plants are designed to separate plutonium from spent nuclear power reactor fuel. This plutonium, although typically not weapon-grade, is still weapon-usable.[34]

While Israel is the only state in the region that reprocesses today for any purpose, both Egypt and Iran have explored reprocessing at a laboratory scale.[35] The IAEA has not reported any steps by Iran toward building a reprocessing facility but the Arak heavy-water reactor (Figure 6) is similar to the heavy-water-moderated, natural-uranium-fueled reactors that India, Pakistan and other countries have used to produce plutonium for their weapons programs.

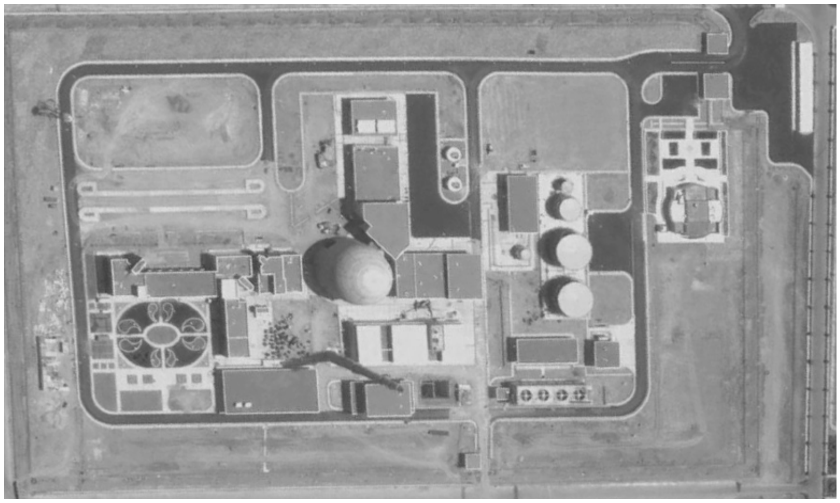

Figure 6. Iran's Arak reactor. The 40 MW-thermal reactor is scheduled to be commissioned in 2014. It could produce annually 10-12 kg of plutonium in its spent fuel, sufficient for one to two nuclear weapons. It is under IAEA safeguards. *Credit: Google Earth*.

Figure 7. The Dair Alzour (Al Kibar) site in Syria in August and October 2007. On 6 September 2007, Israel destroyed the site. In May 2011 the IAEA Director General reported that it was very likely that the destroyed building was a nuclear reactor whose construction should have been declared to the Agency. As a result, in June 2011, the IAEA Board of Governors determined that Syria was in non-compliance with its NPT safeguards agreement. *Credit: Google Earth (August 2007) and Digital Globe/ISIS (October 2007).*

The partly constructed Syrian copy of North Korea's plutonium production reactor, which was destroyed by an Israeli airstrike in 2007 (Figure 7), probably was intended to produce plutonium.[36] It is still not clear where the plutonium would have been separated.

Even if Middle East countries pursue ambitious civilian nuclear power programs, they need not develop reprocessing capabilities. Unlike uranium enrichment, reprocessing is not essential for today's nuclear power plants. Indeed, it increases the cost of nuclear electricity and complicates the problem of nuclear waste disposal by dissolving spent fuel, a stable waste form, and creating multiple new types of radioactive waste that need to be stabilized for disposal.[37]

Civilian reprocessing was launched in the 1960s and 1970s because it was believed that uranium soon would become prohibitively expensive for conventional water-cooled nuclear power reactors, which exploit efficiently only the fission energy stored in chain-reacting uranium-235 (0.7 percent of natural uranium). Liquid-sodium-cooled fast-neutron plutonium-fueled "breeder" reactors were proposed to turn non-chain-reacting uranium -238 (99.3 percent of natural uranium) into chain-reacting plutonium-239.

Although there have been temporary peaks in uranium prices due to fluctuations in anticipated demand, the real long-term cost of uranium has not climbed since 1970.[38] Today uranium accounts for only a few percent of the cost of electricity from new nuclear power plants. The largest portion of the cost of nuclear electricity is due to the capital cost of the plants. Breeder reactors were not commercialized because of their high capital cost, low reliability and safety issues.[39] Nonetheless, India and Russia are building demonstration breeder reactors and China is debating doing so.

A regional ban on reprocessing in the Middle East would be consistent with a worldwide trend away from reprocessing, however. Currently only six of the 31 countries with nuclear power plants reprocess civilian spent fuel on any scale: five nuclear-weapon states (China, France, India, Russia and the United Kingdom) and one non-weapon state, Japan. Both France and Japan, which have policies to recycle the recovered plutonium in the reactors that produced it, have found that plutonium recycle is not economic.[40] Thus far, however, both have found the easiest way to navigate their domestic and bureaucratic nuclear politics is to continue their reprocessing policies. In the absence of new reprocessing contracts, the United Kingdom decided in 2012 to stop reprocessing when its existing contracts are fulfilled – currently projected for 2018.[41]

A ban on plutonium separation in the Middle East should also include a ban on the use of plutonium as reactor fuel. Today only states that reprocess their spent fuel use plutonium as a fuel. In addition to the reprocessing states enumerated above, a few states in Europe (Belgium, Germany, the Netherlands and Switzerland) have shipped their spent fuel to France and the United Kingdom to be reprocessed and either have received or plan to receive the plutonium back in mixed-oxide (MOX, uranium-plutonium) fuel for their reactors. Only the Netherlands has renewed its reprocessing contract with France, however.[42]

A similar proliferation risk would be the irradiation of thorium in a nuclear reactor to produce uranium-233, which, like plutonium, can be chemically separated in a reprocessing plant. Like plutonium, uranium-233 is a nuclear weapons-usable material and has been considered as a possible nuclear fuel.[43] This option would be closed as part of a ban on reprocessing but no country other than India is currently pursuing a thorium/uranium-233 fuel cycle – and India's plans have for the past six decades been more of a vision based on India's large thorium resource than a program.[44]

End the use of HEU as a reactor fuel

HEU is used by some countries as a fuel in research and naval reactors. Six countries in the possible Middle East WMD-free zone defined in Figure 1 currently have research reactors, with a total of three reactors fueled by HEU containing 20 percent or more uranium-235, which is considered weapon-usable (Table 2). With the exception of Israel's Dimona reactor, all of these research reactors and their fuel are under IAEA safeguards.

In September 1990, on the eve of the 1991 "Desert Storm" campaign that drove Iraq's forces out of Kuwait, Saddam Hussein launched a crash program to extract enough HEU for a nuclear weapon from research reactor fuel provided by France and Russia.[45] The effort apparently did not get very far and the fuel was removed from Iraq after the war. It was the attacks of 11 September 2001 and the fears of nuclear terrorism that they inspired, however, that galvanized and made more urgent the long-running but low-level U.S.-led effort to end the use of HEU as a research reactor fuel worldwide.

Technically, converting the remaining HEU-fueled reactors in the Middle East from HEU to low-enriched uranium (LEU, containing less than 20 percent U-235) fuel would be a straightforward task. The reactors shown in Table 2 with fuel enriched to 19–20 percent have already been converted from HEU to LEU. The only remaining HEU fueled reactors are Israel's Research Reactor #1 (IRR-1), provided by the United States, and two Miniature Neutron Source Reactors (MNSRs) provided by China to Iran and Syria.

Israel's IRR-1 is running out of HEU fuel and cannot acquire more from abroad because Israel is not a member of the NPT. An accelerator is being built at Israel's Soreq facility to provide an alternative source of neutrons for research and it is expected that the IRR-1 will be shut down in 2017 or 2018.[46] A shipment of spent HEU fuel from IRR-1 was returned to the United States in January 2010.[47] The remaining spent HEU fuel will be shipped back to the United States after the reactor is shut down.

The MNSRs in Iran and Syria contain only about 1 kg of HEU each – much less than the 25 kg of uranium-235 in HEU used by the IAEA as a rough measure of the quantity required for a simple nuclear weapon. A program to convert MNSRs to operate on 12 percent LEU was launched in 2005 as a cooperative project between the IAEA, China and the United States.[48] The technical analyses of the safety and lifetimes of the LEU cores have been completed. China will soon convert one of its own MNSRs and it is expected the first foreign MNSR (in Ghana) will be converted in 2014.[49] The conversion of the MNSRs in Iran and Syria has been delayed, however, by the controversies over their nuclear programs and the civil war in Syria.

Country	**Research reactor** (date of first operation, fuel supplier)	**Power** (megawatts thermal)	**Fuel enrichment** (% uranium-235)
Algeria	NUR (1989, Argentina)	1	19.7
	Es-Salam (1992, China)	15	10
Egypt	ETRR-1 (1961, Russia)	2	10
	ETTR-2 (1997, Argentina)	22	19.75
Iran	Teheran Research Reactor (1967, Iran)	5	19.75
	Subcritical assembly (1992, China	0	natural
	Subcritical assembly (1992, China)	0	natural
	Critical assembly (1995, China)	0	natural
	MNSR (1994, China)	0.03	90 (1 kg)
	Arak (not completed, Iran)	40	natural
Israel	IRR-1 (Soreq, 1960, USA)	5	93
	IRR-2 (Dimona, 1963, Israel)	26-150	natural
Libya	IRT-1 (1981, Russia)	10	19.75
Syria	MNSR (1996, China)	0.03	90 (1 kg)

Table 2. Research reactors in the Middle East and the uranium-235 enrichment of their fuel.[50]

In the future, a shared high-power research reactor fueled by LEU with state of the art experimental equipment could provide a superior venue for much of the scientific work currently carried out at the national facilities in the Middle East and could also help build transparency between the region's nuclear researchers. This shared reactor could be one of the existing research reactors in the region with a power of ten megawatts or higher (see Table 2) or a new reactor.

Shared use of costly research facilities by university, national laboratory and industry users is a well-established practice in Europe and the United States. In the Middle East, a first example is project SESAME (Synchrotron light for Experimental Science and Applications in the Middle East) located in Jordan. Its membership cuts across the Middle East's national divides and, as of 2013, included Bahrain, Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, the Palestinian Authority, and Turkey.[51]

Another use of HEU as fuel is in naval nuclear propulsion reactors. So far, such use has been limited to nuclear weapon states. The United States, United Kingdom, Russia and India use HEU as naval fuel. France has shifted from HEU to LEU fuel and China is believed to use LEU fuel. In April 2013, the head of Iran's Atomic Energy Organization, Fereidoun Abbasi-Davan, announced that:

> "in some cases ... such as ships and submarines, if our researchers have a need for greater presence under the sea, we must build small engines whose construction requires fuel enriched to 45 to 56 percent. In this case, it's possible we would need this fuel."[52]

There is no need for naval propulsion reactors to use HEU fuel, however. As noted above, France's naval reactors today use LEU fuel.[53] The naval reactor that Brazil, the first non-nuclear-weapon state to do so, is developing is to be LEU fueled.[54] If Iran or any other country in the region were to acquire nuclear submarines or ships, they could be LEU fueled. There is therefore no need for any state to produce HEU for reactor fuel. It would strengthen the nuclear non-proliferation regime if the countries with HEU-fueled naval reactors would design their future propulsion reactors to use LEU fuel.[55]

Limit enrichment of uranium to less than 6 percent

Weapon-grade HEU is typically enriched to 90 percent or greater in uranium-235. For safeguards purposes, however, the IAEA treats uranium enriched above 20 percent as a direct weapon-usable material. Even 20 percent is a much higher level of enrichment than the less than 5 percent enriched uranium that is used to fuel commercial nuclear power reactors worldwide today. The only nuclear power reactor operating in the Middle East today – at Bushehr in Iran – is fueled with uranium enriched to about 3.5 percent.[56]

In the near term, Middle Eastern states could import the enriched nuclear fuel for their power reactors, as do almost all other states with nuclear power reactors. Should Middle East states choose to develop uranium enrichment as part of their nuclear power programs, as Iran is doing, they could agree to limit uranium enrichment to no more than six percent, the level set for France's new George Besse II centrifuge enrichment plant, which supplies enriched uranium for France's nuclear ships as well as for its nuclear power plants.[57] If a new type of power reactor was introduced whose advantages justify a higher fuel enrichment, this upper limit could be revised by agreement. (As is discussed below, however, we believe that it would strengthen the nonproliferation regime if all national enrichment plants – not just those in the Middle East – were placed under effective multinational management.)

The only reactors in the Middle East that will use uranium enriched to levels higher than six percent in the foreseeable future are research reactors. After shut-down or conversion of the remaining three research reactors in the zone that are fueled by HEU, the highest enriched research reactor fuel will be 19.75 percent, i.e. slightly less than the internationally agreed 20 percent boundary between enrichment levels that are considered weapon-usable and those that are not. These reactors require only a small amount of fuel, however. For example, a 20-MWt reactor operating for 200 days per year requires only about 50 kg of 20 percent enriched uranium annually. In comparison, the annual requirement for a typical 1000-MWe (~3000 MWt thermal) power reactor is about 20,000 kg of 4.5 percent enriched uranium.

Almost all 20 percent enriched uranium used in research reactors worldwide is provided by Russia and the United States today by blending down excess weapon-grade uranium. That supply should last for decades. If more is ever required, a small part of a single enrichment plant could supply global requirements.

If countries are concerned that both Russia and the United States might cut off their supplies for reasons not related to IAEA safeguards issues, an IAEA-controlled reserve of 19.75 percent enriched uranium could be established. A reserve of 5 percent uranium is currently being established by the IAEA in Kazakhstan in case a country cannot obtain LEU on the commercial market and "no issues relating to safeguards implementation in the requesting State are under consideration by the IAEA Board of Governors."[58]

Iran has not been able to obtain 20 percent enriched fuel for the Teheran Research Reactor (TRR) under conditions acceptable to it because of the dispute over Iran's enrichment program. The TRR received its only shipment of fuel from Argentina in 1992. Since 2010, therefore, Iran has been producing its own 20 percent enriched uranium. This has raised concerns that Iran could use its stock of 20 percent enriched uranium as feed material to quickly make weapon-grade uranium. By the time natural uranium (which contains 0.7 percent uranium-235) has been enriched to 20 percent uranium-235, more than 90 percent of the enrichment work required to produce weapon-grade uranium has been done.[59] Put simply, the higher the enrichment level of a stock of uranium, the quicker it can be enriched to weapon-grade.

Iran could suspend production of 20-percent enriched uranium today, however, since, as of August 2013, it had produced enough (>250 kg) to fuel the Teheran Research Reactor for 10 to 27 years.[60] Iran has repeatedly expressed its willingness to end its enrichment to 20 percent if it can obtain a reliable supply of 20 percent enriched uranium for import.

Just-in-time enrichment

Iran is the only country in the Middle East that is enriching uranium for civilian purposes. According to the IAEA's August 2013 report, Iran had a stockpile of 6774 kg of UF6 gas, containing about 4500 kg of uranium, enriched to up to 5 percent uranium-235.[61] An additional 53 kg of UF6 enriched to up to 3.34 percent has been converted into UO2, the form that is used in the fuel of the Bushehr nuclear power plant. Iran's only other use of its up-to-5 percent-enriched uranium has been for feed to produce 20 percent enriched uranium for TRR, of which it has produced, as already noted, a 10 to 27 year supply.

The stockpiling of uranium enriched up to 5 percent uranium-235 is a concern. Enrichment from 5 percent to 90 percent uranium-235 takes about one quarter as much enrichment work as starting from natural uranium.[62] A stock of 4500 kg of 3.5–5 percent enriched uranium would be sufficient to produce 141–216 kg of 90 percent enriched uranium – enough for five to ten nuclear explosives.[63]

Iran could increase confidence in its intentions if it did not stockpile even up-to-5 percent enriched UF6. It could do this by fabricating this low-enriched uranium into fuel for the Bushehr reactor. Until it has the capability to do so, it could export most of its low-enriched uranium to Russia for fabrication into Bushehr fuel, keeping only as much as it requires for fuel-fabrication research and development.

A pause in the buildup of Iran’s enrichment capacity

Currently, Iran has no enrichment requirements for nuclear power reactors. The fuel for its Bushehr reactor, the only nuclear power reactor in the region, is supplied by Russia. Under Western pressure, Russia delayed the completion of the Bushehr reactor and delivery of fuel, creating concern in Iran about depending upon Russia for fuel. Iran also justifies its enrichment program by pointing to plans to build 20 nuclear power reactors and the need for reliable access to LEU to fuel these reactors.[64] Iran argues that agreements to supply it with enriched uranium have been broken in the past; after the 1979 revolution, France refused to provide Iran with enriched uranium from the Georges Besse gaseous diffusion enrichment plant in which Iran had invested.[65]

As Iran continues to build up its enrichment capacity, international concern will grow about the resulting shortening of the time Iran would need to produce enough 90 percent enriched uranium for a nuclear explosive from even natural uranium, if it chose to do so. As of August 2013, Iran appeared to have an enrichment capacity of about 8600 SWU/yr from about 10,400 operating first-generation IR-1 centrifuges.[66] An additional 12,000 IR-1 centrifuges were at various stages of installation. In addition, Iran was in the process of installing about 3000 IR-2m centrifuges, each with perhaps four times the enrichment capacity of the centrifuges that it has used to date.[67] The centrifuges are located at the enrichment facilities at Natanz and Fordow (Figure 8).

Figure 8. Iran’s Natanz enrichment plant (left) under construction in 2003, with the now buried centrifuge halls shown in red outline, and the Fordow enrichment plant (right) in 2012 with arrows indicating four tunnel entrances. In both cases, the centrifuge halls are underground for protection from attack. Both plants are under IAEA safeguards. *Source: Google Earth.*

It takes about 170 SWU to make a kg of weapon-grade uranium from natural uranium. At a capacity of 8600 SWU/yr, it would be possible to make about 50 kg a year or enough for about two nuclear explosives a year. This is an overestimate, however, since Iran's cascades are configured to produce LEU. Estimates based on more detailed modeling find that the production time would be about a year and a half plus an initial month for setting up connections between pairs of cascades.[68] Once Iran begins operating the centrifuges currently being installed, it would more than triple its enrichment capacity and cut the time to make two weapons worth of HEU to about half a year. As the second centrifuge hall at Natanz is filled and advanced centrifuges that are under development are phased in, this "breakout" time would shrink further.

Iran could insure against a possible nuclear fuel cutoff by the less threatening and relatively low-cost alternative of purchasing a stockpile of up to ten years of fuel for the Bushehr reactor. This would have the added benefit of allowing time to build confidence in the peaceful intent of Iran's enrichment program.[69]

Multinational control of enrichment

The inherent proliferation dangers of uranium enrichment and plutonium separation (reprocessing) have been long recognized. The *Report on the International Control of Atomic Energy* – better known as the Acheson-Lilienthal Report – that was prepared for the U.S. State Department in 1946 argued that both uranium enrichment and reprocessing of irradiated uranium to recover plutonium are inherently "dangerous activities," in that they provide easy routes to nuclear weapons.[70] The authors therefore proposed that uranium enrichment and plutonium separation facilities be taken out of national control and placed under the management of an independent international organization.

The Acheson-Lilienthal proposal was not adopted because of the Cold War. Since then national enrichment and reprocessing programs have spread – in most cases as part of nuclear weapons programs, but also to some non-weapon states. Today, among the 24 non-weapon states with nuclear power plants, five (Brazil, Germany, Iran, Japan and the Netherlands) have operating uranium enrichment plants and one (Japan) has a reprocessing plant.

In 2003, international and regional concern about Iran's decision to build a national uranium enrichment program led Mohammed ElBaradei, then Director General of the IAEA, to revive a proposal for multinational control of all enrichment facilities, including in the nuclear-weapon states.[71] Adopting this model globally would avoid the objections – as expressed, for example, by the Non-aligned Movement of countries[72] – to imposing a new discriminatory nuclear regime on the non-weapon states and Iran in particular. The crisis over Iran's enrichment program is so dangerous, however, that a diplomatic solution of that crisis should not be made hostage to a global agreement.

As the only country in the Middle East with a civilian national enrichment program, Iran could play a pioneering role in strengthening the non-proliferation regime by embracing multinational control of enrichment and advancing a global shift away from national enrichment plants. One option would be for other countries in the region with plans to construct nuclear power plants to join in the management of Iran's enrichment plants and help set the goals for the program and fund any expansion. To realize this objective, a Treaty establishing a Middle East WMD-free zone could require that all parties set aside their NPT Article IV rights to peaceful national enrichment and reprocessing programs.[73]

The United Arab Emirates (UAE) is building four nuclear power reactors but agreed in its bilateral Agreement on Nuclear Cooperation with the United States that it "shall not possess sensitive nuclear facilities within its territory or otherwise engage in activities within its territory for, or relating to, relating to the enrichment or reprocessing of material."[74] The UAE is contracting for enrichment services from Europe and Russia.[75]

The UAE-U.S. Agreement on Nuclear Cooperation concludes with a caveat, however, that provides that the conditions accepted by the UAE:

> "shall be no less favorable in scope and effect than those which may be accorded, from time to time, to any other non-nuclear weapon State in the Middle East in a peaceful nuclear cooperation agreement. If this is, at any time, not the case, at the request of the Government of the United Arab Emirates the Government of the United States of America will provide full details of the improved terms agreed with another non-nuclear-weapon State in the Middle East, to the extent consistent with its national legislation and regulations and any relevant agreements with such other non-nuclear weapon State, and if requested by the Government of the United Arab Emirates, will consult with the Government of the United Arab Emirates regarding the possibility of amending this Agreement so that the position described above is restored."[76]

Verification arrangements

Given the mutual distrust resulting from the region's history of wars and proliferation, any Middle East WMD-free zone will need robust verification. To build confidence on the road to a Middle East WMD-free zone, all states in the region will have to become more open. Above, we have discussed a step-by-step process in which Israel would end its production of fissile materials, declare its stockpiles and begin to place portions of them under IAEA safeguards for disposition. In parallel, the non-weapon states in the region should offer full transparency to the IAEA, starting with Comprehensive Safeguards Agreements and Additional Protocols (AP).

Comprehensive Safeguards Agreements

Under NPT Article III.4, all non-weapon states must complete a Comprehensive Safeguards Agreement with the IAEA within 180 days of joining the Treaty.[77] As noted earlier, these agreements require a state to declare its nuclear materials and activities and establish a system of IAEA inspections to verify the declaration including through measurements during on-site visits.

Code 3.1. Prior to the discovery of Iraq's secret nuclear program in 1991, the IAEA limited its verification activities to sites with declared nuclear materials, as per NPT Article III.1, which states:

> "The safeguards required by this article shall be applied to all source or special fissionable material in all peaceful nuclear activities within the territory of such State, under its jurisdiction, or carried out under its control anywhere."[78]

Iraq was not in violation of its safeguards agreement with the IAEA in the 1980s because, according to the Code 3.1 of the Subsidiary Arrangements in its Comprehensive Safeguards Agreement that was in force at that time, countries were not required to inform the IAEA that they were building new nuclear facilities until 180 days before introducing nuclear material into them. In 1992, after the discovery of Iraq's clandestine enrichment program, however, the IAEA's Board of Governors revised Code 3.1 to require countries to report new nuclear facilities: "as soon as the decision to construct or to authorize construction has been taken, whichever is earlier."[79]

All non-weapon states with Comprehensive Safeguards Agreements have accepted this change except Iran, which did so provisionally between 2003 and 2006 but then reverted to the original Code 3.1 after the IAEA Board of Governors referred its case to the UN Security Council. Given Iran's plans to expand its nuclear infrastructure, which at times have included a declared intent to build additional enrichment plants, Iran should commit to abide by revised Code 3.1 as a confidence-building measure and ensure that the IAEA has the opportunity to verify the design information for all planned nuclear facilities.

Additional Protocols

After the discovery in 1991 of Iraq's clandestine efforts to acquire uranium enrichment technologies, the IAEA also developed and its Board approved in 1997 a voluntary AP to buttress the Comprehensive Safeguards Agreements. The AP requires states that ratify it to provide the IAEA with information on:[80]

- Nuclear-fuel-cycle-related research and development not involving nuclear materials and plans for such activities and for construction of fuel-cycle facilities in the succeeding ten-year period;
- The uses and contents of facilities on nuclear sites that are not declared to contain nuclear material and, upon request, "at locations identified by the Agency outside a nuclear site which the Agency considers might be functionally related to the activities of that site";
- Uranium and thorium mining and imports and processing prior to the stage where these materials are pure enough to be placed under safeguards;
- Quantities and uses of nuclear material considered to be too small to be placed under IAEA safeguards;
- Any processing of wastes containing nuclear materials on which IAEA safeguards had been terminated;
- Exports and imports of specified nuclear equipment or equipment or materials that could be used in the construction of reactors, heavy-water production facilities or fuel-cycle facilities; and
- Any other information "identified by the Agency on the basis of expected gains in effectiveness or efficiency, and agreed to by [a country] on operational activities of safeguards relevance at facilities and at locations outside facilities where nuclear material is customarily used."

As of the end of 2012, eight Middle East states had ratified the AP (Table 3):

- The UAE, which currently has nuclear power reactors under construction;
- Bahrain, Jordan and Kuwait, which undertook exploratory activities related to the possibility of launching nuclear programs but suspended them following the Fukushima accident;[81]
- Iraq and Libya, both of which had secret nuclear-weapon programs under governments that were subsequently overthrown; and
- Mauritania.

As noted earlier, Iran signed the AP in 2003 and voluntarily complied with it pending ratification until 2006 when its case was referred to the UN Security Council. Iran has still not ratified the AP.

Among the other Middle East non-weapon states that have not signed the AP:

- Syria refused to cooperate with IAEA efforts to clarify the nature of the program associated with the alleged nuclear reactor that Israel destroyed in 2007;[82]
- Saudi Arabia has been discussing a very large nuclear power program;
- Egypt has had plans to ask for vendor proposals for a nuclear power plant;[83] and
- Qatar is interested in nuclear power but has not made a decision yet.[84]

At this time, none of the six remaining non-signatories of the AP: Djibouti, Lebanon, Oman, Somalia, Sudan and Yemen, is known to have a nuclear program of any significance.[85]

As part of the confidence-building process required before a Middle East WMD-free zone can be achieved, the countries in the zone that have not yet done so should ratify the Additional Protocol.

	Additional Protocol in force	**Steps toward AP ratification**	**Comprehensive Safeguards Agreement not in force**
Bahrain	2011		
Comoros	2009		
Djibouti		Signed 2010	Signed 2010
Egypt		None	
Iran		Signed 2003	
Iraq	2012		
Israel			X
Jordan	1998		
Lebanon		None	
Kuwait	2003		
Libya	2006		
Mauritania	2009		
Oman		None	
Qatar		None	
Saudi Arabia		None	
Somalia		None	X
Sudan		None	
Syria		None	
United Arab Emirates	2010		
Yemen		None	

Table 3. Status of Additional Protocol and Comprehensive Safeguards Agreements for states in a potential Middle East WMD-free zone as of September 2013.[86]

The five NPT nuclear weapon-states (the United States, UK, Russia, France and China) all have signed and ratified limited versions of the AP with the IAEA that cover, at most (in the case of the United States) their peaceful nuclear activities.[87] As part of the confidence-building process, Israel too could negotiate an AP with the IAEA that covers its peaceful nuclear-related activities.

Transparency measures beyond the Additional Protocol

Iran's period of compliance with the AP, from 2003 to 2006, allowed the IAEA to understand Iran's uranium enrichment R&D and centrifuge production activities. It also enabled the IAEA to discover some or all of Iran's undeclared R&D activities relating to centrifuge enrichment, laser enrichment and reprocessing. Finally, the IAEA obtained evidence suggesting that Iran had carried out R&D relating to nuclear-weapons design. This led in 2006 to the IAEA Board of Governors finding that it was:

> "necessary for Iran to [*inter alia*] implement transparency measures, as requested by the Director General, including in GOV/2005/67, which extend beyond the formal requirements of the Safeguards Agreement and Additional Protocol, and include such access to individuals, documentation relating to procurement, dual use equipment, certain military-owned workshops and research and development as the Agency may request in support of its ongoing investigations." [88]

Subsequently, the United Nations Security Council, acting with the authority given to it by Article 41 of the UN charter, declared that "Iran shall provide such access and cooperation as the IAEA requests … to resolve all outstanding issues, as identified in IAEA reports."[89]

This decision gave the IAEA an extraordinarily broad license to request information and access in Iran. During 2012, the IAEA requested repeatedly that it be able to visit in particular a facility at the Parchin military site where Iran allegedly had carried out implosion experiments.[90] Iran refused to comply with the demand.[91]

The other countries in the Middle East will have to demonstrate a high level of cooperation and transparency if Israel is to be willing to go all the way to complete, verified nuclear disarmament. The experience of South Africa's nuclear disarmament offers a useful precedent.

In the 1970s and 1980s, South Africa had a nuclear weapon program that produced weapon-grade uranium and assembled six nuclear weapons. In 1990, however, the weapons were dismantled and, in 1991, South Africa joined the NPT as a non-weapon state, declaring and placing its HEU under IAEA safeguards. To confirm that South Africa's declaration was complete, the IAEA inspected South Africa's nuclear facilities, including those that had been involved in South Africa's nuclear weapon program, as well as their historical operating records, and performed consistency checks based on that physical and documentary evidence. The IAEA also visited suspect sites. The process took a few years (1991-1993).

When the IAEA finally declared that it was satisfied with South Africa's declaration, it based its confidence in good part on the cooperation that had been provided by South Africa's government. The lead inspectors wrote in an article published in the *IAEA Bulletin* that their conclusions:

> "had a strong technical basis and were significantly supported by the transparency and openness of the South African authorities with respect to access to information and locations, in particular the stated and demonstrated willingness of the authorities to facilitate access to any location that the IAEA may identify." [92]

As these examples demonstrate, the IAEA's work in supporting the creation of a WMD-free zone in the Middle East could be facilitated by enhanced access that goes beyond the standard safeguards agreement and the AP.[93]

A regional nuclear fuel-cycle and verification organization

Even having all the states in the region ratify their own Additional Protocols to their Comprehensive Safeguards Agreements with the IAEA and go beyond them in the above respects would likely be insufficient to establish mutual confidence within the region about the absence of clandestine nuclear activities. Similarly, there could be a lack of sufficient confidence inspired by the CWC inspection system managed by the OPCW. The BWC currently has no verification system.

It therefore is likely that, as part of the verification of a Middle East WMD-free zone, neighbors will want to be able to inspect each other's WMD-relevant activities. This will require establishing a regional verification structure.[94]

Brazil and Argentina have provided a precedent. After they ended their nuclear weapon programs in 1990, the first step they took on verification was to establish, in July 1991, a bilateral inspection system, the Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials (ABACC), which undertook its first inspections in July 1992. Only in 1994 did Argentina and Brazil agree to place all of their nuclear facilities under IAEA safeguards in a "Quadripartite Agreement" involving Argentina, Brazil, ABACC and the IAEA.[95] ABACC was modeled on Euratom's inspectorate, which shares safeguards responsibilities with the IAEA in the non-weapon states of the European Union and also safeguards the peaceful nuclear activities of Europe's two nuclear-weapon states, France and the United Kingdom.

As already noted, if nuclear power capacity in the Middle East continues to grow, it is possible that at some point, shared regional uranium conversion and enrichment facilities could offer an economical way to service the fuel needs of all the power programs in the region. Commercially competitive uranium enrichment plants currently have capacities of a few to more than ten million SWU per year – enough to support at least a few tens of today's light water power reactors. Under any reasonable scenario, it will take at least two decades to install nuclear power capacity of this scale in the region.

The verification organization would provide regional as well as IAEA monitoring, transparency and improved safeguards on all nuclear materials used in any enrichment facility in the region and in the conversion of uranium into UF_6 for enrichment or from UF_6 after enrichment. It also would oversee the mining and purification and import of uranium and the operations of any fuel-cycle facilities in the region.

Conclusion

Given the political turmoil in the Middle East, the continued possession of nuclear weapons by Israel, use of chemicals weapons in the civil war in Syria, failure to resolve the Iranian nuclear crisis, and the continuing occupation of Palestine, it is unlikely that a Middle East WMD-free zone can be established anytime soon. It should, however, be possible to make progress on a number of building blocks for such a zone.

Israel should undertake initial steps to show that it is seriously interested in eliminating its nuclear weapons and stocks of unsafeguarded fissile materials in the framework of a Middle East WMD-free zone. Israel could start by ending any further production of plutonium and highly enriched uranium, declaring the sizes of its stocks of these materials and beginning to place portions of its fissile material stocks under IAEA safeguards for elimination.

All states in the region could take measures of nuclear restraint that would build confidence that a Middle East zone free of all weapons of mass destruction would be feasible, robust and effectively verifiable. These restraints, if adopted more widely, also would serve to strengthen the global non-proliferation regime:

- Banning plutonium separation and ending the use of plutonium and of HEU as a reactor fuel;
- Limiting the enrichment of uranium to less than six percent, banning the stockpiling of enriched uranium for which there are no immediate requirements and interim limits on enrichment capacities to levels that don't inspire fear of breakout;
- Placing uranium mining, milling, imports, conversion and enrichment facilities under the oversight of a regional organization as well as the IAEA;
- Universal acceptance of the Additional Protocol; and
- Agreement on transparency measures beyond the Additional Protocol when requested by the IAEA.

Finally, discussions should begin on the structure and functions of a regional organization to supplement the verification activities of the IAEA and OPCW. Such an organization would provide countries of the region an additional basis for confidence that all their neighbors are complying with the obligations that they will undertake by joining a Middle East zone free of nuclear weapons and all other weapons of mass destruction.

Endnotes

[1] First Committee of the UN General Assembly resolution 3263 (XXIX), "Establishment of a nuclear-weapon-free zone in the region of the Middle East," 9 December 1974.

[2] A Latin American nuclear weapon free zone was first proposed at the United Nations in 1962 by Brazil.

[3] Proposal by Egypt's President, Hosni Mubarak, submitted to the United Nations on 16 April 1990, see Mohamed Nabil Fahmy, "Egypt's Disarmament Initiative," *Bulletin of the Atomic Scientists*, November 1990.

[4] "Nuclear-Weapon-Free Zones (NWFZ) At a Glance," Arms Control Association, September 2012, www.armscontrol.org/factsheets/nwfz.

[5] 1995 Review and Extension Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons, 17 April to 12 May 1995, New York 1995, Final Document, NPT/CONF.1995/32 (Part I), Annex, Resolution on the Middle East, www.un.org/disarmament/WMD/Nuclear/1995-NPT/pdf/Resolution_MiddleEast.pdf.

[6] The President of the 1995 NPT Review and Extension Conference, Ambassador Jayantha Dhanapala of Sri Lanka, has said, "I personally do not believe the Conference would have adopted the indefinite extension without a vote if the [Middle East] resolution issue had not been settled as it was." Jayantha Dhanapala with Randy Rydell, *Multilateral Diplomacy and the NPT: An Insider's Account*, United Nations Institute for Disarmament Research, Geneva, 2005, p.57.

[7] US Department of State, "2012 Conference on a Middle East Zone Free of Weapons of Mass Destruction (MEWMDFZ)", 23 November 2012.

[8] On Israel's occupation and blockade, see for instance the annual report to the United Nations General Assembly by the Special Rapporteur on the Situation of Human Rights in the Palestinian Territories Occupied since 1967, Richard Falk. The most recent report was 19 September 2012, http://daccess-dds-ny.un.org/doc/UNDOC/GEN/N12/515/86/PDF/N1251586.pdf?OpenElement.

[9] Harriet Sherwood, "Israelis and Palestinians meet for peace talks," *The Guardian*, 14 August 2013.

[10] "OPCW to Review Request from Syria," Organisation for the Prohibition of Chemical Weapons, 13 September 2013, www.opcw.org/news/article/opcw-to-review-request-from-syria. See also "Assad: Syria needs one year to destroy chemical weapons," *BBC*, 19 September 2013, www.bbc.co.uk/news/world-middle-east-24155674. For the U.S.-Russian agreement on verifiably destroying Syria's chemical weapons, see U.S. Department of State, Washington, D.C., 14 September 2013, www.state.gov/r/pa/prs/ps/2013/09/214247.htm.

[11] United Nations Security Council Resolution 2118, 27 September 2013, www.un.org/News/Press/docs//2013/sc11135.doc.htm.

[12] Statement by President Hassan Rouhani of Iran, United Nations General Assembly, New York, 24 September 2013, http://gadebate.un.org/sites/default/files/gastatements/68/IR_en.pdf.

[13] *Effective and Verifiable Measures Which Would Facilitate the Establishment of a Nuclear-weapon-free Zone in the Middle East*, (Report of the Secretary General, United Nations, 1991) paragraphs 65, 66.

[14] Israel could not join the NPT as a weapon state because of Article IX.3, which limits nuclear weapon-state membership to countries that tested nuclear explosives before 1967.

[15] We are grateful to Ambassador Paul Meyer of Canada for this suggestion.

[16] "African Nuclear Weapon Free Zone Treaty (Treaty of Pelindaba)," Disarmament Treaties Database, United Nations Office of Disarmament Affairs, disarmament.un.org/treaties/t/pelindaba.

[17] Disarmament Treaties Database, United Nations Office of Disarmament Affairs, disarmament.un.org/treaties.

[18] United Nations Secretary-General announcement of Syria's ratification of Chemical Weapons Convention, 14 September 2013, http://treaties.un.org/doc/Publication/CN/2013/CN.592.2013-Eng.pdf.

[19] Avner Cohen, "Crossing the threshold: the untold nuclear dimension of the 1967 Arab-Israeli War and its contemporary lessons," *Arms Control Today*, June 2007.

[20] Robert Norris and Hans Kristensen, "Global nuclear weapons inventories, 1945–2010," *Bulletin of the Atomic Scientists*, July/August 2010. See also the excerpt of the Defense Intelligence Agency's secret threat assessment, *A Primer on the Future Threat: The Decades Ahead: 1999-2020* reprinted in Rowan Scarborough, *Rumsfeld's War* (Regnery, 2004), p. 197, where estimates are given for Israel's warhead stockpile for 1999 (60-80) and projected to 2020 (65-86).

[21] "Israel" in *Global Fissile Material Report 2010: Balancing the Books-Production and Stocks* (International Panel on Fissile Materials, 2010).

[22] Krypton-85 capture is not impossible. Campaigns were carried out at a naval fuel reprocessing plant in the United States and a pilot plant in Germany. The systems used were still in development, however, Patricia Paviet-Hartmann, W. Kerlin, and S. Bakhtiar, *Treatment of Gaseous Effluents Issued from Recycling – A Review of the Current Practices and Prospective Improvements* (Idaho National Laboratory, INL/CON-10-19961, 2010); and E. J. Hutter, R. Von Ammon, W. Bumiller, and G. Neffe, "Final results and consequences of the development of a cryogenic krypton separation system," *Proceedings of the 19th DOE/NRC Nuclear Air Cleaning Conference,* Seattle, WA, 18-21 August 1986.

[23] "Treaty on Open Skies," U.S. Department of State, www.state.gov/t/avc/trty/102337.htm.

[24] R. Scott Kemp, "Initial analysis of the detectability of UO_2F_2 aerosols produced by UF_6 released from uranium conversion plants," *Science & Global Security*, 16, 2008, p. 116; and "Source terms for routine UF_6 emissions," *Science & Global Security*, 18, 2010, p. 119.

[25] R. Scott Kemp, "A performance estimate for the detection of undeclared nuclear-fuel reprocessing by atmospheric ^{85}Kr," *Journal of Environmental Radioactivity*, 99, 2008, p. 1341.

[26] A mixture of deuterium (D) and tritium can be used to "boost" the yield of a small fission explosive with a burst of neutrons (n) from the reaction D+T –> He^4 + n, see e.g., Frank von Hippel, Harold Feiveson, and Christopher Paine, "A low-threshold nuclear test ban," *International Security*, Vol. 12, No. 2, Fall 1987, p. 135.

[27] One alternative source could be a particle-accelerator-driven neutron source that could create tritium (T) through the reaction: n + lithium-6 –> T + helium-4. Only a relatively modest neutron source would be required since less than 5 percent of the neutrons produced by the Dimona reactor are available for tritium production. The Dimona reactor is fueled with natural uranium. Uranium-238 constitutes 99.3 percent of natural uranium and most of the neutrons in a heavy-water natural-uranium-fueled reactor that are not required to maintain the chain reaction are absorbed in uranium-238 to produce plutonium-239. See the discussion in *Global Fissile Material Report 2010* (International Panel on Fissile Materials, 2010), p. 114. A commercially available 150-MeV, 2 mA isochronous cyclotron could produce about one neutron per proton on a spallation target or about 1.5 percent the number of excess neutrons produced by the Dimona reactor fueled with natural uranium and operating at 70 MW-thermal, R. Scott Kemp, "Nuclear proliferation with particle accelerators," *Science & Global Security*, 13, 2005, p. 183.

[28] "Israel" in *Global Fissile Material Report 2010, op. cit.*

[29] *Ibid.*

[30] Victor Gilinsky and Roger Mattson, "Revisiting the NUMEC affair," *Bulletin of the Atomic Scientists,* March/April 2010, p. 61.

[31] Alex Gasner and Alexander Glaser, "Nuclear archaeology for heavy-water-moderated plutonium production reactors," *Science & Global Security*, 19, 2011, p. 223.

[32] For details of the scenarios, see "Israel" in *Global Fissile Material Report 2010: Balancing the Books-Production and Stocks* (International Panel on Fissile Materials, 2010).

[33] On the weapon-usability of uranium-233, see e.g. Robert Alvarez, "Managing the uranium-233 stockpile of the United States," *Science & Global Security* 21, 2013, pp.53-69.

[34] In 1977, Japan decided, as a token concession to the United States, to mix its separated plutonium with an equal amount of unenriched uranium. During the G.W. Bush Administration, AREVA similarly proposed to modify the design a reprocessing plant that it wished to sell the United States so that plutonium would never be completely separated from uranium. South Korea is currently arguing that pyroprocessing is "proliferation resistant" because it does not separate the minor transuranic elements and some short-lived lanthanide fission products from the plutonium. All these mixtures are weapon-usable, however, and the reprocessing facilities could easily be modified to produce pure plutonium. See e.g., Jungmin Kang and Frank von Hippel, "Limited proliferation-resistance benefits from recycling unseparated transuranics and lanthanides from light-water reactor spent fuel," *Science & Global Security,* 13, 2005, p. 169; and R. Bari et al, *Proliferation Risk Reduction Study of Alternative Spent Fuel Processing,* Brookhaven National Laboratory, BNL-90264-2009-CP, 2009.

[35] Pierre Goldschmidt, "The IAEA Reports on Egypt: Reluctantly?" Carnegie Endowment for International Peace, 2 June 2009; and Report by the IAEA Director General, *Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran*, 15 November 2004.

[36] Report by the IAEA Director General, *Implementation of the NPT Safeguards Agreement in the Syrian Arab Republic*, 30 August 2012.

[37] See e.g. Frank von Hippel, "The costs and benefits of reprocessing," in *Nuclear Power's Global Expansion: Weighing its Costs and Risks*, Henry Sokolski, ed., Strategic Studies Institute, 2010.

[38] R. Price, "An analysis of uranium exploration and price," *Facts and opinions, NEA News*, 2005 – No. 23.1, p. 8 from 1970 to 2002 in constant dollars; and US Energy Information Administration, *2012 Uranium Marketing Annual Report,* Table S1a 1994-2012, in current dollars.

[39] See e.g., *Fast Breeder Reactor Programs: History and Status* (International Panel on Fissile Materials, 2010).

[40] J.M. Charpin, B. Dessus and R. Pellat, *Report to the Prime Minister [of France]: Economic Forecast Study of the Nuclear Power Option* , 2000, Tables on pp. 43, 56, 214., 215; and Japan Atomic Energy Commission, "Estimation of Nuclear Fuel Cycle Cost and Accident Risk Cost (Statement) 2011.

[41] UK Nuclear Decommissioning Authority, *Oxide Fuels: Preferred Option*, 2012.

[42] The Netherlands has one 40-year-old, 0.5-GWe power reactor.

[43] See for instance, Robert Alvarez, "Managing the uranium-233 stockpile of the United States," *op. cit*.

[44] M.V. Ramana, *The Power of Promise: Examining Nuclear Energy in India* (Penguin-Viking, 2012).

[45] Rodney Jones et al, *Tracking Nuclear Proliferation* (Carnegie Endowment for Peace, 1998), pp. 190-1.

[46] Dan Williams, "Israel to phase out civilian atomic reactor by 2018," *Reuters*, 20 March 2012,

[47] Frank Munger, "Spent HEU fuel from Israel," *knoxnews.com*, 21 January 2010.

[48] "CRP on Conversion of Miniature Neutron Source Research Reactors (MNSR) to Low Enriched Uranium (LEU)" www.iaea.org/OurWork/ST/NE/NEFW/Technical_Areas/RRS/mnsr.html.

[49] James Matos, Argonne National Laboratory, personal communication, 18 February 2013.

[50] IAEA Research Reactor Database, available at nucleus.iaea.org/RRDB/RR/ReactorSearch.aspx; International Atomic Energy Agency, *Nuclear Research Reactors in the World*, Reference Data Series Number 3, IAEA, Vienna, 2000.

[51] SESAME: Synchrotron-light for Experimental Science and Applications in the Middle East, www.sesame.org.jo/sesame.

[52] "AEOI head: Iran to enrich uranium to 50% if nuclear-powered vessels needed," *Fars News Agency*, 16 April 2013.

[53] The next (*Suffren*) class of French nuclear attack submarines, to be commissioned starting in 2017 will use uranium enriched only to levels used in civilian light water nuclear power plants and therefore can be supplied by the same plant that enriches fuel for France's power reactors, Ministère de la Défense, Le Programme Barracuda, Le Sous-marin D'attaque Du 21ème Siècle, Dossier de Presse, 22 December 2006, available at groups.google.com/forum/?hl=fr&fromgroups=#!topic/noticiarionaval/jQ7ygev_n6s.

[54] "In Brazil, fuel for land prototype first core and, probably, for first-of-kind SSN [nuclear-powered attack submarine] use LEU (4-6%), similar to *Otto Hahn* [a German cargo ship that operated with nuclear power from 1968-1979]," personal communication from Leonam dos Santos Guimaraes, 29 July 2011, former Nuclear Propulsion Program Coordinator at the Brazilian Navy Technological Center at Sao Paulo.

[55] In its report on the Fiscal Year 2009 budget authorization bill, the Senate Armed Services Committee included the following language: "The committee directs the Office of Naval Reactors to review carefully options for using low enriched uranium fuel in new or modified reactor plants for surface ships and submarines." Senate Report 110-335: Senate Arms Service Committee, National Defense Authorization Act for Fiscal Year 2009, p. 515, http://beta.congress.gov/congressional-report/110th-congress/senate-report/335/1.

[56] "Iran begins loading Bushehr nuclear reactor," *BBC*, 21 August 2010.

[57] "Ceremony marks the first cascade at Georges Besse II," Areva, 26 May, 2009, www.urenco.com/page/216/Ceremony-marks-the-first-cascade-at-Georges-Besse-II.aspx.

[58] The complete set of requirements and the current status of the IAEA Fuel Bank may be found at www.iaea.org/OurWork/ST/NE/NEFW/Assurance-of-Supply/iaea-leu-bank.html.

[59] Production of one kg of 90 percent enriched uranium from natural uranium with 0.4 percent U-235 left in the depleted uranium (DU) requires 169 SWU. Production from 20 percent enriched uranium with 3.5 percent U-235 in the DU requires 10.5 SWU.

[60] The IAEA has reported that, as of 16 August 2013, Iran had produced about 372 kg of UF6 enriched "up to 20%" in uranium-235. About 2/3 of this weight (about 252 kg) would be uranium. Of the 324 kg, 185 kg (containing 125 kg of uranium) had been fed into a conversion process to produce 87 kg of uranium in U3O8. The IAEA has verified that some of this U3O8 has been used to manufacture 21 fuel assemblies for the Teheran Research Reactor (TRR), Report by the IAEA Director General, *Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions in the Islamic Republic of Iran*, 28 August 2013.

An average fuel assembly in the TRR core contains 18 fuel plates, each with 77.5 grams of uranium. The fabricated fuel therefore contains about 29 kg of uranium. A full core of 27 fuel assemblies would contain about 37.8 kg of 20 percent uranium. [TRR core design information from Kazem Farhadi and Samad Khakshournia, Nuclear Research Center, Atomic Energy Organization of Iran, "Feasibility study for Tehran Research Reactor power upgrading," *Annals of Nuclear Energy* Vol. 35 (2008) p. 1177.] The TRR is a 5 MW (thermal) reactor. Such a reactor consumes about 1.2 g of uranium-235 per MWd. At 40 percent burnup of the uranium-235 content, the TRR would consume 5x(1.2/0.4)/0.2 = 75 g of LEU per per full-power day. In 1992, Argentina, supplied Iran with 115.8 kg of LEU fuel. If the fuel was consumed by 2012, that would correspond to an average consumption of about 6 kg of LEU per year or full-power operation for the equivalent of 80 days per year. Iran claimed 60 equivalent full power days in its 2009 report to the IAEA (http://nucleus.iaea.org/RRDB/RR/HeaderInfo.aspx?RId=214) but that was in a situation in which it was running out of fuel. Twelve percent of the world's research reactor operated for 210 or more days per year (http://nucleus.iaea.org/RRDB/Content/Util/UtilHigh.aspx), which would be equivalent to an annual demand of 16 kg of 20 percent-enriched uranium for a 5 MW reactor. Operating between 80 to 210 full-power days per year, assuming 35 percent losses in the conversion and fuel production process, the 252 kg of 20 percent uranium that Iran had produced as of May 2013 would be sufficient for 10 to 27 years.

[61] Report by the Director General, *Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions in the Islamic Republic of Iran*, 22 May 2013.

[62] Production of one kg of 90 percent enriched uranium from natural uranium with 0.4 percent uranium-235 left in the depleted uranium (DU) requires 169 SWU. Production from 5 percent enriched uranium with 0.7 percent uranium-235 in the DU requires 43 SWU.

[63] Assuming that the depleted uranium "tails" from the enrichment process had an enrichment of 0.7 percent (as in natural uranium).

[64] In February 2013, the Atomic Energy Organization of Iran announced 16 sites for future power reactors, www.presstv.ir/detail/2013/02/23/290389/iran-to-build-16-nuclear-power-plants.

[65] Oliver Meier, "Iran and foreign enrichment: a troubled model," *Arms Control Today*, January 2006. The story is complicated by the fact that immediately after the 1979 revolution Iran cancelled its contract for purchase of enrichment work from the plant. For other pre-1979 nuclear contracts with Iran that were cancelled, see *Chronology of Iran's Nuclear Programme, 1957-2007*, available at www.oxfordresearchgroup.org.uk.

[66] Iran produced 2253 kg of UF6 enriched up to 5 percent (we assume 3.5 percent) between 22 October 2012 and 10 August 2013 (0.72 years). We assume that the depleted uranium contained 0.4 percent uranium-235. Iran produced 49 kg of ~20 percent UF6 in the Natanz pilot plant from 3.5 percent enriched uranium between 16 September 2012 and 16 August 2013 (0.92 year) and 94 kg in the Fordow enrichment plant between 18 November 2012 and 16 August 2013 (0.74 year). This assumes 0.7 percent uranium-235 in the depleted uranium. Report by the Director General, *Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions in the Islamic Republic of Iran*, 28 August 2013.

[67] David Albright and Christina Walrond, *Iran's Advanced Centrifuges*, Institute for Science and International Security, 18 October 2011, available at isis-online.org.

[68] If the centrifuge cascades were arranged to produce weapon-grade (90 percent enriched) uranium through three intermediate stages (3.5 percent, 20 percent and 60 percent). William C. Witt, Christina Walrond, David Albright, and Houston Wood, *Iran's Evolving Breakout Potential*, Institute for Science and International Security, October 2012.

[69] Frank von Hippel, "National fuel stockpiles: an alternative to a proliferation of national enrichment plants?" *Arms Control Today*, September 2008, p. 20.

[70] *A Report on the International Control of Atomic Energy*, prepared for the Secretary of State's Committee on Atomic Energy, 16 March 1946, fissilematerials.org/library/ach46.pdf, chapter V.

[71] Mohammed ElBaradei, "Towards a safer world," *The Economist*, 16 October 2003.

[72] "The Ministers reaffirmed the basic and inalienable right of all states to develop research, production and use of atomic energy for peaceful purposes, without any discrimination and in conformity with their respective legal obligations. Therefore, nothing should be interpreted in a way as inhibiting or restricting the right of states to develop atomic energy for peaceful purposes. They furthermore reaffirmed that States' choices and decisions, including those of the Islamic Republic of Iran, in the field of peaceful uses of nuclear technology and its fuel cycle policies must be respected." *Statement on the Islamic Republic of Iran's Nuclear Issue*, XV Ministerial Conference of the Non-Aligned Movement Tehran, Islamic Republic of Iran, 27-30 July 2008.

[73] Article IV.1 of the Non-Proliferation Treaty 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 and in conformity with articles I and II of this Treaty." The debate is over whether Iran's enrichment program is exclusively for "peaceful purposes," as Iran asserts, or whether a major motivation is to provide Iran with a nuclear-weapons option.

[74] *Agreement for Cooperation between the Government of the United States and the Government of the United Arab Emirates Concerning Peaceful Uses of Nuclear Energy*, U.S. Government Printing Office, 21 May 2009, www.gpo.gov/fdsys/pkg/CDOC-111hdoc43/pdf/CDOC-111hdoc43.pdf.

[75] World Nuclear Association, "Nuclear Power in the United Arab Emirates," www.world-nuclear.org.

[76] *Agreement for Cooperation between the Government of the United States and the Government of the United Arab Emirates, op. cit.*

[77] The Comprehensive Safeguards Agreement template used by the IAEA is published by the IAEA on its website as INFCIRC/153 (corrected), *The Structure and Content of Agreements between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons.*

[78] "Source material" is purified natural or depleted uranium, or thorium that could be irradiated to produce plutonium or U-233. "Special material" is enriched uranium, plutonium or U-233, including in spent fuel, IAEA, *Safeguards Glossary*, 2001, p. 31.

[79] *Subsidiary arrangement to the agreement between The Government of […] and the International Atomic Energy Agency for the application of safeguards in connection with the treaty on the non-proliferation of nuclear Weapons* (IAEA, 2 November 2011), www.iaea.org/OurWork/SV/Safeguards/documents/Online_Version_SG-FM-1170_--_Model_Subsidiary_Arrangement_Code_1-9.pdf, Code 3.1.2.

[80] The template for the Additional Protocols is published on the IAEA website as INFCIRC/540 (corrected), *Model Protocol Additional to the Agreement between State (S) and the International Atomic Energy Agency for the Application of Safeguards*.

[81] World Nuclear Association, "Nuclear Power in Jordan"; www.world-nuclear.org; "Bahrain postpones nuclear energy plans," *Trade Arabia*, 17 October 2012.

[82] Report by the IAEA Director General, *Implementation of the IAEA Safeguards Agreement in the Syrian Arab Republic*, 30 August 2012.

[83] "After revolution, Egypt turns to nuclear," *Nuclear Intelligence Weekly*, 21 September 2012, p. 5.

[84] "Qatar's N-power plan 'economically feasible,'" 10 February 2012, nucpros.com/content/qatar's-n-power-plan-'economically-feasible'.

[85] As noted above, Djibouti and Somalia do not have Comprehensive Safeguards Agreements in force.

[86] IAEA, *Status List: Conclusion of Safeguards Agreements, Additional Protocols and Small Quantities Protocols*, as of 24 September 2013, www.iaea.org/safeguards/documents/sir_table.pdf.

[87] For a discussion of the respective Additional Protocols agreed by the NPT nuclear weapon states, see chapter 6, *Global Fissile Material Report 2007*.

[88] IAEA Board of Governors, *Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran*, Resolution adopted on 4 February 2006.

[89] UN Security Council Resolution 1737, 23 December 2006; Article 41 of the UN Charter states that "the Security Council may decide what measures not involving the use of armed force are to be employed to give effect to its decisions, and it may call upon the Members of the United Nations to apply such measures. These may include complete or partial interruption of economic relations and of rail, sea, air, postal, telegraphic, radio and other means of communication and the severance of diplomatic relations."

[90] See e.g., Report of the Director General of the IAEA to the IAEA's Board of Governors, *Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions in the Islamic Republic of Iran*, 16 November 2012, paragraphs 43-45. The basis for the IAEA's concerns were laid out in the 8 November 2011 Report of the Director General of the same title, Annex C, paragraphs 41-51.

[91] During 2004-2005 Iran did give the IAEA access to a different part of the Parchin site. Iran has engaged in prolonged negotiations with the IAEA, including demanding that, in exchange for the maximum level of transparency measures (including implementation of Additional Protocol) and constraints on its enrichment

program (such as halting production of 20 percent enriched uranium and capping the enrichment level at 5 percent), the UN Security Council relax the sanctions imposed on Iran and recognize its legitimate rights for enrichment under NPT.

[92] Adolf von Baeckmann, Garry Dillon, and Demetrius Perricos, "Nuclear verification in South Africa," *IAEA Bulletin* 1, 1995, p. 42; the official IAEA report was made to the IAEA General Conference, *The Denuclearization of Africa*, GC(XXXVII)/1075, 9 September 1993.

[93] In the case of continuing centrifuge enrichment programs, this would include procedures for accounting for production of key centrifuge components and the assembly and installation of centrifuges; and continuous video monitoring of key points in centrifuge cascades, such as the feed and withdrawal points.

[94] A former senior Israeli official argued in late 2012 that a Middle East WMD-free zone "will have to involve the establishment of pertinent regional institutions to implement it and the backbone of the Zone's verification scheme and ultimately also its enforcement mechanism must be regional in nature. This holds true even when pertinent international institutions exist (such as the IAEA and to a lesser extent also the OPCW)." Ariel Levite, formerly principal deputy director general of the Israeli Atomic Energy Commission, "*Reflections on 'The regional security environment and basic principles for the relations of the members of the zone*," background paper presented at the EU Non-Proliferation Consortium, Second Seminar to Promote Confidence Building in Support of a Process Aimed at Establishing a Zone Free of WMD and Means of Delivery in the Middle East, Brussels, 5-6 November, 2012, www.nonproliferation.eu/documents/backgroundpapers/levite.pdf. The OPCW is the Organization for the Prohibition of Chemical Weapons, the agency charged with implementing verification of the Chemical Weapons Convention.

[95] Mitchell Reiss, *Bridled Ambition: Why Countries Constrain Their Nuclear Capabilities* (Johns Hopkins, 1995), pp. 61-64.

About the authors

Frank N. von Hippel is a Professor of Public and International Policy emeritus and senior research physicist at Princeton University and co-founder of its Program on Science and Global Security. During 1993-4, he served as Assistant Director for National Security in the White House Office of Science and Technology Policy. He is also a co-founder and co-chair of the International Panel on Fissile Materials (IPFM).

Seyed Hossein Mousavian is an associate research scholar at the Program on Science and Global Security at Princeton University's Woodrow Wilson School of Public and International Affairs. He is a former diplomat who served as Iran's Ambassador to Germany (1990-1997), head of the Foreign Relations Committee of Iran's National Security Council (1997-2005) and as spokesman for Iran in its nuclear negotiations with the international community (2003-2005). He is a member of IPFM.

Emad Kiyaei is a researcher at Princeton University's Program on Science and Global Security, in Woodrow Wilson School of Public & International. Previously, he was an Associate at the Center for International Conflict Resolution (CICR) at Columbia University, focusing on Middle East and Iranian affairs.

Harold A. Feiveson is a Senior Research Analyst emeritus at Princeton University's Woodrow Wilson School of Public and International Affairs and co-founder of the Program on Science and Global Security. He is a member of IPFM.

Zia Mian is a research scientist at Princeton University's Woodrow Wilson School of Public and International Affairs and co-deputy chair of the IPFM.

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Program on Science and Global Security
Princeton University
221 Nassau Street, 2nd Floor
Princeton, NJ 08542, USA

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