Fissile Material Controls in the Middle East
Steps Toward a Middle-East Nuclear-Weapon-Free Zone

Zia Mian, Alexander Glaser, Frank von Hippel, Seyed Mousavian,
Emad Kiyaei, and Harold Feiveson

Program on Science and Global Security
Princeton University

ABSTRACT. This paper proposes possible initiatives for fissile material control that could serve as initial steps toward an eventual Middle East Nuclear-Weapon-Free Zone. These initiatives include actions that Israel could take toward 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. Specific measures include no separation of plutonium, no use of highly enriched uranium or plutonium as fuel, and no national enrichment plants. We also propose and review regional verification arrangements that would help build confidence in the absence of secret nuclear weapon programs. Taken together, these building blocks would serve to bring a Middle East nuclear-weapon-free zone closer and make the zone more robust when it is in force.

Background

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). The proposal drew on the model of the 1967 treaty for a Latin American nuclear weapon-free zone. 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. For the purposes of this paper, we adopt the suggestion from the 1991 study commissioned by the UN 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." The focus here is on the challenges of establishing a nuclear weapon free zone (NWFZ) in the region.[1]

We propose a number of key measures that could lay the basis for a Middle East NWFZ. These measures envision (a) ending the separation of plutonium, (b) limiting the level of enrichment of uranium and its national control, and (c) the problem of Israel's existing stocks of plutonium and possibly highly enriched uranium that are outside safeguards. Since strong verification measures will be critical for a viable NWFZ in the region, the discussion offers elements for a robust regional safeguards, monitoring, and verification regime.

Principles and Building Blocks

The effort to establish a Middle East NWFZ would have to grapple with Israel's existing nuclear arsenal, the history of covert proliferation efforts by Iraq, Syria, Egypt, and Libya in violation of their commitments under the NPT, Iran's nuclear program, and with Israel's broader security concerns about its neighbors. For Israel—and perhaps other states in the region—moving towards such a zone will likely require intermediate steps that establish strong new technical and political barriers to any future attempts to seek nuclear weapons capability. While national policy makers in Middle East states may seek to sequence such steps as a way to make trade-offs, each of the intermediate steps presented below have nonproliferation and disarmament value in their own right and states should be encouraged to adopt them as soon as they are able to do so.

1. Ban on the Separation of Plutonium. Israel's nuclear arsenal is based on plutonium that was produced by irradiating natural uranium fuel in a heavy-water-moderated reactor at the Negev Nuclear Research Center near Dimona. Supplied by France in the 1950s to jumpstart Israel's weapons program, the power of the reactor has reportedly been increased several-fold from its original design value of 24–26 MW (thermal) to 40 MW and then 70–140 MW.[2] The plutonium was chemically separated from the irradiated uranium in an underground reprocessing plant adjoining the reactor. By ending reprocessing of accumulated discharged fuel and shutting down the Dimona reactor, Israel would cap the amount of plutonium that it could use to make nuclear weapons.[3] These steps could be verified with fair confidence at first without access to the site and later under a managed access arrangement.

Beyond Dimona, there is a more general concern that natural-uranium fueled research reactors provide latent proliferation capabilities since, in principle, significant quantities of plutonium can be extracted from their spent fuel. In 2007, Israel's air force destroyed a partly constructed graphite-moderated plutonium production reactor in Syria. Reportedly, the reactor was a copy of North Korea's Yongbyon reactor, in which case it could have produced about 7 kg of weapon-grade plutonium per year.[4] Today, Iran's under construction heavy-water-moderated 40 MW Arak reactor (IR-40) raises similar concerns since it could produce almost 9 kg of plutonium per year. Over time, spent fuel containing plutonium sufficient for several nuclear weapons would accumulate in the reactor core and spent fuel pool.

Modifications to the Arak reactor have been proposed in order to reduce potential plutonium production rates. One proposal would reduce annual plutonium production to less than one kilogram by converting the reactor to 5%-enriched fuel and reducing the power level to 10–20 MW.[5] More generally, to avoid similar proliferation concerns associated with plutonium production in research reactors, there could be an agreement to prohibit or phase-out natural-uranium fueled reactors in the region altogether.

While Israel is the only state in the Middle East that reprocesses spent fuel today for any purpose, both Egypt and Iran have explored reprocessing at a laboratory scale.[6] Even if Middle East countries pursue ambitious civilian nuclear power programs, they need not develop reprocessing capabilities. No sound economic or environmental justification exists for using plutonium for civilian applications. Reprocessing and stockpiling separating plutonium creates serious proliferation risks as the material could be used to make nuclear weapons. Safeguarding reprocessing plants is particularly difficult and costly. In sum, under this proposal, separating plutonium from spent fuel, even if undertaken for strictly peaceful purposes would therefore be banned in the region.

2. Restrictions on Uranium Enrichment. Iran operates the only civilian enrichment facilities in the Middle East today and therefore possesses the capability to produce enough weapon-grade HEU for a first nuclear weapon in a matter of months. It is widely recognized that Iran's breakout capability to produce the material for such weapons needs to be constrained. The enrichment program relies on gas centrifuge technology. Israel may also have a small-scale centrifuge-based uranium enrichment capability.[7]

In contrast to plutonium separation, access to low-enriched uranium is required to fuel light-water reactors, which include both typical research and power reactors. Centrifuge enrichment plants pose significant proliferation concerns because they can be quickly reconfigured for HEU production.[8] To address these concerns, we propose the following restrictions on uranium enrichment plants in the region:

- A general prohibition on the production of highly enriched uranium;
- A limit on the maximum uranium enrichment of 5–7 percent U-235; and
- A move toward multilateral arrangements substituting national enrichment.

There are precedents for accepting restrictions on uranium enrichment capability. The United Arab Emirates renounced enrichment technology and capability as part of its 2009 nuclear cooperation agreement with the United States. Also, as part of the current talks on proliferation concerns about Iran's nuclear program, as set out in the Joint Plan of Action, Iran and the P5+1 (China, France, Germany, Russia, the United Kingdom, and the United States) agreed that one element of a mutually acceptable to-be-agreed comprehensive solution would be "a mutually defined [Iranian] enrichment programme with mutually agreed parameters consistent with practical needs, with agreed limits on scope and level of enrichment activities, capacity, where it is carried out, and stocks of enriched uranium, for a period to be agreed upon."[9] As part of the Joint Plan of Action agreed in November 2013, Iran committed that for a six month (possibly renewable) period it would not enrich uranium above 5%.[10] Going further, partners in the region have a strong interest in limiting enrichment to 5–7%, which is sufficient for fuel used in light-water power reactors and provides an extra margin against breakout.

To make progress toward an eventual prohibition of national enrichment plants, it will be important to avoid further developments in the opposite direction. For example, Iran is planning to acquire an enrichment capacity sufficient to fuel the Bushehr power reactor by the time the current fuel supply contract with Russia ends in 2021. This would be equivalent to a ten-fold increase of Iran's current enrichment capacity and is likely to make adoption of a multilateral framework later on more difficult.

One suggested compromise would be for Iran to agree to a moratorium on increasing its operating enrichment capacity until it needs to begin making fuel for Bushehr.[11] In the meantime, Iran could continue research, development, and field-testing of next-generation centrifuges. After selecting one or more advanced centrifuge models that are able to meet the standards for commercial-scale operation (e.g. separative performance and long-term reliability), Iran could begin to manufacture the required number of centrifuge components for the 2021 target SWU capacity and store these components under IAEA supervision at a central location. The key components requiring monitoring would include the centrifuge rotors and casings. Iran could also agree to refrain from making preparations for the installation of these centrifuges. Since they would be under IAEA monitoring, removal of components from storage would be quickly detected. Overall, such a strategy would not shorten the time for breakout and provide flexibility for a longer-term solution. This transparency arrangement should be made permanent.

At the same time as a medium-term solution to the confrontation over Iran's nuclear program is being agreed, it would be wise to begin dealing with the underlying problem, namely national control over enrichment facilities. One option would be for the P5+1 and Iran to agree as part of the final "comprehensive solution" to embark immediately on designing a regime for effective multinational arrangements for enrichment in the Middle East, ensuring a reduced risk of future Middle Eastern nuclear crises.[12] Specifically, the negotiating parties could establish a working committee on multilateralization of the enrichment program, invite other partners of the region to join, and set a five-year deadline to reach agreement, i.e., a date well before 2021. A regionally managed and operated enrichment plant would undercut incentives for Middle East states to follow Iran in developing national enrichment facilities.

3. Declarations of fissile material stockpiles and step-by-step safeguards. As the only non-NPT member in the region, Israel's stockpiles of plutonium produced at its Dimona reactor remain cloaked in secrecy.[13] The countries in the Middle East that use HEU as research reactor fuel (Israel, Iran, Syria) have already declared these stocks to the IAEA.

A step toward enabling a Middle East NWFZ and nuclear disarmament would be for Israel to declare the size of its stocks of unsafeguarded fissile materials. Plutonium production at Dimona over its 50-year lifespan has been estimated to be on the order of 800 ± 125 kilograms, enough for some 200 nuclear weapons.[14] While declaring the size of its stocks of separated plutonium, and also possible stocks of HEU, Israel would not be required to disclose what portion resides in its nuclear arsenal nor disclose any other information about its nuclear weapons program and arsenal. Israel would be called upon to 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.

Verification Arrangements

Given the mutual distrust resulting from the region's history of wars and proliferation, any Middle East NWFZ will need robust verification. Some elements of a possible verification arrangement are discussed below.

1. Additional Protocol and Transparency Measures. The countries in the zone that have not yet done so should ratify the Additional Protocol to their IAEA Comprehensive Safeguards Agreements. The AP *inter alia* grants inspector access to all parts of the nuclear fuel cycle, provides 'complementary access' to all buildings on a nuclear site, and allows collection of environmental samples at sites other than declared locations.[15]

As part of the confidence-building process, Israel could negotiate an AP with the IAEA that covers its peaceful nuclear-related activities. Israel would not be the first of the nuclear weapon states outside the NPT to do so. India signed an AP with the IAEA in 2009 and ratified the protocol in June 2014. The five NPT nuclear weapon states also have signed and ratified AP agreements with the IAEA.

2. Regional Nuclear Fuel-cycle and Verification Organization. Middle East states will almost certainly want to be able to inspect their neighbors' nuclear activities directly as part of a NWFZ and not rely solely on the IAEA. A similar arrangement was developed between Argentina and Brazil as part of the Latin American NWFZ. A Middle East regional verification organization would complement IAEA monitoring, transparency, and safeguards on all nuclear materials used in any enrichment facility in the region and in the conversion of uranium into uranium hexafluoride (UF_6) for enrichment or from UF_6 after enrichment. Applied measures could go beyond the IAEA and oversee uranium mining and purification, uranium imports, and the operations of any fuel-cycle facilities in the region.

3. Monitoring and Verification Tools. While full transparency and on-site inspections are indispensable elements of a successful regional and IAEA verification system, many of the initial steps outlined above for moving toward regional zero could be verified initially with fair confidence without direct access to the sites in question. Among the conditions that could be verified with standoff detection methods are reactor operating status, the absence of reprocessing, and the absence of other undeclared fuel-cycle activities, including perhaps those related to clandestine uranium enrichment.

One important monitoring and verification tool, especially in the early stages, would be 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.[16] 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. There are grounds for optimism that airborne sensors could help enable detection of undeclared nuclear facilities in the Middle East.

A. Reactor Status. Airborne infrared sensors should be able to verify the shutdown status of a nuclear reactor by detecting the reduction of the temperatures of the outside of a reactor containment building or a reactor's cooling towers (Figure 1). Likewise, airborne infrared sensors could help detect the signatures of undeclared reactors should they exist somewhere in the region.

B. Clandestine reprocessing. The absence of reprocessing 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. Previous analyses based on experimental and simulated data indicate a high detection probability for krypton-85 even for single detectors that are more than fifty kilometers away from the point of emission.[17] Figure 2 illustrates a hypothetical example. It should be possible to detect emissions of krypton-85 with near certainty, and discriminate them against the krypton background from reprocessing activities elsewhere in the world, if sensors are placed around the site boundaries of a known reprocessing plant.

C. Clandestine enrichment. The absence of undeclared enrichment, especially when based on centrifuges, is much harder to detect than reprocessing. Emission signatures from centrifuge plants are extremely weak, and it might be more promising to detect undeclared UF_6 production instead.[18] When leaked from plant equipment, UF_6 gas

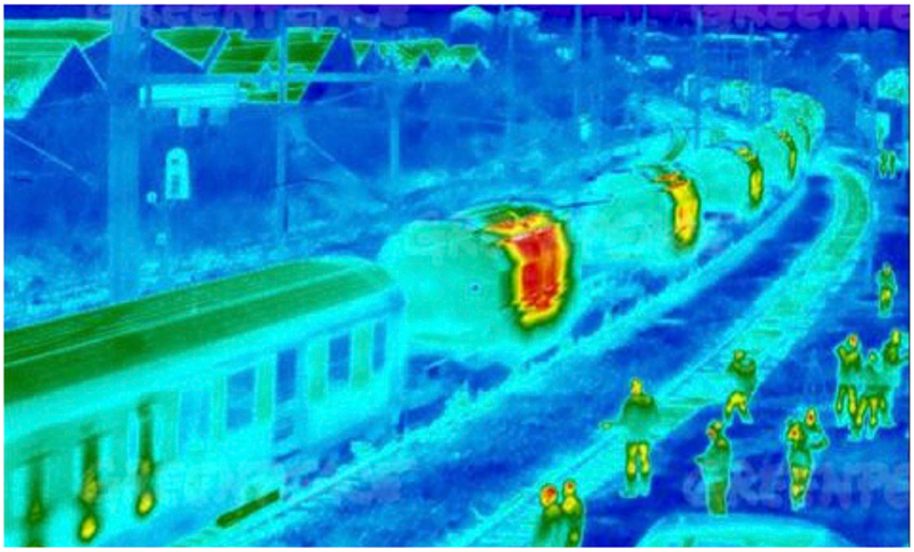

Figure 1. Remote detection of thermal signatures. Infrared sensors on aircraft and drones could reliably confirm the operational status of nuclear reactors in the region. Such sensors are already allowed as part of the Open Skies Treaty. The picture shows a spent fuel transport cask with a power level of 35 kW thermal. The estimated surface temperature is 30 °C compared to about 20 °C of the passenger car on the left. *Source: Greenpeace.*

reacts with moisture in the air and degrades to microscopic UO_2F_2 particles. Very few public analyses exist of source term estimates from uranium enrichment or conversion plants combining both experimental and simulated data.[19] The difficulty of detecting clandestine uranium enrichment highlights the potential role and importance of cradle-to-grave approaches to the nuclear fuel cycle.[20]

4. Opportunities for Collaboration and Emerging Verification Techniques. In addition to standard tools used by the IAEA, there are a number of emerging technologies that could play a role in the verification of a NWFZ in the Middle East or elsewhere. Developing these verification technologies and approaches offers opportunities for regional collaboration and capacity-building.

Near real-time satellite imagery offers such an example. The satellite imagery provider Skybox Imaging (now owned by Google) plans to accept tasks "up to 10 minutes before the satellite flies over" and deliver the imagery "in as little as 20 minutes of collection." Tasks are scheduled on a "first-come, first-served" basis,[21] which could be particularly important in this regional context, where equal access of all partners to verification capabilities is critical.

Another opportunity for collaborative verification capacity-building in the region could be for Middle East countries to set up a regional data sharing, analysis, and technical training process focused on existing or planned Comprehensive Test Ban Treaty

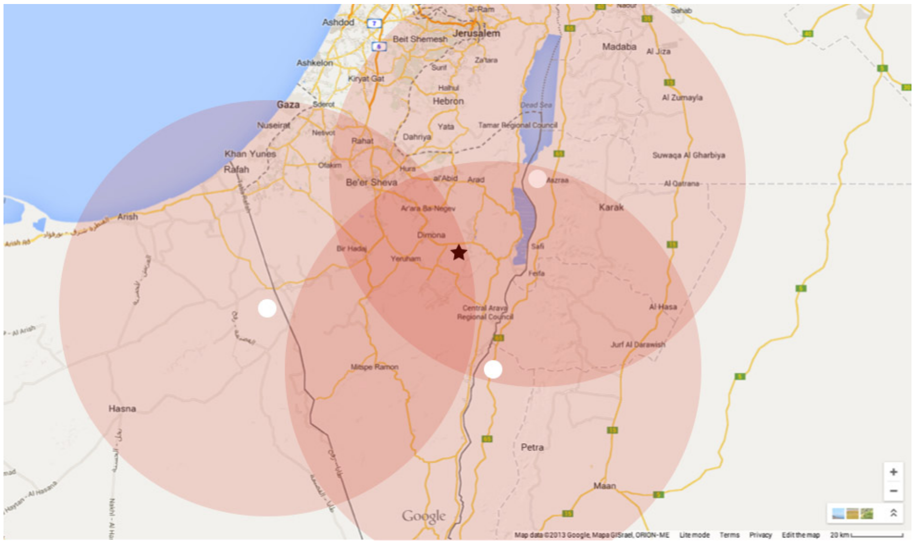

Figure 2. Even a small number of krypton-85 detector stations in the Middle East could provide assurance of the absence of undeclared reprocessing in the region. For illustrative purposes, three hypothetical stations in Jordan and Egypt with a detection range of 80 km are shown. The symbol indicates the Dimona site in the Negev desert. As part of a collaborative effort, sensors could be placed close to known former nuclear facilities to confirm their operational (shutdown) status. *Source: Google Maps.*

(CTBT) monitoring stations. This could also include countries that have not yet signed the CTBT (Saudi Arabia, Somalia, and Syria). Of special interest could be the radionuclide monitoring stations that look for radio-xenon and other isotopes and particles from nuclear tests. There are currently stations in Kuwait City, Misrata (Libya), and Nouakchott (Mauritania); one additional station is planned for Tehran. Similar stations could look for krypton-85 from reprocessing as part of a NWFZ verification network.

One particularly challenging aspect of a verified NWFZ in the Middle East will be to obtain confidence in the completeness of Israel's fissile material declaration. In principle, 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.[22] 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. This total could be checked after the dismantlement of Israel's last nuclear weapons and placing of the recovered fissile material under international safeguards, which would be the final step in its disarmament. By committing publicly in advance 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.

Conclusion

Given the political turmoil in the Middle East, the continued possession of nuclear weapons by Israel, the use of chemical weapons in the civil war in Syria in 2013, renewed violent conflict in Iraq, failure to resolve the Iranian nuclear crisis, and the continuing occupation of Palestine, it is unlikely that a Middle East NWFZ can be established anytime soon. It should, however, be possible to make progress on a number of building blocks for such a zone. The measures proposed here constitute the essential technical steps toward a Middle East region free from nuclear weapons.

A great deal of political work remains before these initial measures might be endorsed and implemented, but garnering consensus that they are indeed the logical, practical next steps on the road to global zero in the region would prepare the ground for rapid progress toward implementation when the political circumstances become auspicious.

Endnotes

[1]For the broader discussion, see F. von Hippel, S. H. Mousavian, E. Kiyaei, H. A. Feiveson and Z. Mian, *Fissile Material Controls in the Middle East: Steps toward a Middle East Zone Free of Nuclear Weapons and all other Weapons of Mass Destruction,* Report of the International Panel on Fissile Materials, October 2013.

[2]For a detailed discussion of various production scenarios, see Chapter 8 ("Israel") in Global Fissile Material Report 2010. Balancing the Books: Production and Stocks, International Panel on Fissile Material, Princeton NJ, December 2010.

[3]It is believed that Israel's stockpile of weapon-grade plutonium is much larger than needed to support the nuclear arsenal that it currently has.

[4]This assumes a power level of 25 MW thermal, 300 effective-full-power days per year, and an average discharge burnup of 500 MWd/ton. The plutonium concentration in the spent fuel is about 0.5 g/kg.

[5]A. Ahmad, F. von Hippel, A. Glaser, and Z. Mian, "A Win-Win Solution for Iran's Arak Reactor," *Arms Control Today,* April 2014.

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

[7]Global Fissile Material Report 2010, *op. cit.,* p. 115.

[8] A. Glaser, "Characteristics of the Gas Centrifuge for Uranium Enrichment and Their Relevance for Nuclear Weapon Proliferation," *Science & Global Security,* 16, 2008.

[9] *Joint Plan of Action,* Geneva, November 24, 2013, eeas.europa.eu/statements.

[10] *Joint Plan of Action, op. cit.*

[11] A. Glaser, Z. Mian, S. H. Mousavian, and F. von Hippel, "Agreeing on Limits for Iran's Centrifuge Program: A Two-Stage Strategy," *Arms Control Today,* July/August 2014.

[12] A. Glaser et al., "A Two-Stage Strategy," *op. cit.*

[13] Israel is also believed to have clandestinely obtained about 300 kilograms of weapon-grade uranium from a U.S. naval fuel fabrication facility during the 1960s. V. Gilinsky and R. J. Mattson, "Did Israel steal bomb-grade uranium from the United States?," *Bulletin of the Atomic Scientists,* April 2014; see also, "Revisiting the NUMEC Affair," *Bulletin of the Atomic Scientists,* 66 (2), March 2010.

[14] Chapter 8 ("Israel") in *Global Fissile Material Report 2010. Balancing the Books: Production and Stocks,* International Panel on Fissile Material, Princeton NJ, December 2010.

[15] *Model Protocol Additional to the Agreement between State(s) and the International Atomic Energy Agency for the Application of Safeguards,* INFCIRC/540 (corrected), International Atomic Energy Agency, Vienna, 1997.

[16] P. Jones, *Open Skies: Transparency, Confidence-Building, and the End of the Cold War,* Stanford Security Studies, July 2014.

[17] R. S. Kemp and C. Schlosser, "A Performance Estimate for the Detection of Undeclared Nuclear-fuel Reprocessing by Atmospheric ^{85}Kr," *Journal of Environmental Radioactivity,* 99, 2008, pp. 1341–1348.

[18] R. S. Kemp, "Initial Analysis of the Detectability of UO_2F_2 Aerosols Produced by UF_6 Released from Uranium Conversion Plants," *Science & Global Security,* 16 (3), 2008, pp. 115–125.

[19] R. S. Kemp, "Source Terms for Routine UF_6 Emissions," *Science & Global Security,* 18 (2), 2010, pp. 119–125.

[20] Such a "Cradle to Grave" approach has been proposed by Austria in 2009, *Communication dated 26 May 2009 received from the Permanent Mission of Austria to the Agency enclosing a working paper regarding Multilateralisation of the Nuclear Fuel Cycle,* INFCIRC/755, International Atomic Energy Agency, Vienna, June 2, 2009.

[21] *SkyNode,* Data Sheet, Skybox Imaging, June 2014, www.skyboximaging.com.

[22] A. Gasner and A. Glaser, "Nuclear Archaeology for Heavy-water-moderated Plutonium Production Reactors," *Science & Global Security,* 19, 2011, pp. 223–233.