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Nuclear Energy and Proliferation

Nuclear Issues Paper No. 4

BY OTFRIED NASSAUER

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The Author

Otfried Nassauer was born in 1956. He studied theology and founded the Berlin Information Center for Transatlantic Security (BITS), which he has directed since 1991. For over 20 years he has worked as an independent journalist in the fields of military and international security, writing about nuclear weapons, NATO policy, European security, military technology, weapons monitoring, arms trade, land mines, small arms and German security policy. He also provides commentary and expert opinion on security policy and weapons monitoring for a number of television and radio stations. He has authored and edited numerous books. For more information on his publications, see www.bits.de.

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By Otfried Nassauer

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Contact:
Heinrich Böll Foundation Regional Office for Southern Africa, PO Box 2472; Saxonwold, 2132; South Africa. Phone: +27-11-447 8500. Fax: +27-11-447 4418. info@boell.org.za
Heinrich Böll Foundation, Rosenthaler Str. 40/41, 10178 Berlin, Germany.
Tel.: ++49 30 285 340; Fax: ++49 30 285 34 109; info@boell.de; www.boell.de/nuclear

Introduction

Any civilian nuclear fuel cycle and especially some of the elements thereof confront the world with certain security-related risks. Nuclear materials, nuclear know-how, and technology can be proliferated. Nuclear experts can travel or migrate. This is and has been well known for decades. History provides us with telling examples. The very existence of a wide range of specific precautionary measures such as nonproliferation policies, specific export controls, personnel screening, and reliability programs for employees are additional proof per se that proliferation risks are real.

Throughout the Cold War concerns about nuclear "diffusion" or "proliferation" mostly focused on states trying to obtain materials, technology, or know-how for nuclear weapons. Many different countries and their nuclear programs came under suspicion. In the sixties and early seventies Germany, India, Israel, Japan, and Sweden were some of the countries under scrutiny. In the mid-seventies and eighties Argentina, Brazil, Egypt, India, Iran, Iraq, Pakistan, South Korea, Taiwan, and South Africa were among those seen as countries to be cause for concern. Since the nineties, Iraq, Iran, Pakistan, and North Korea have been on top of the list. Almost all non-nuclear countries starting or working on a nuclear research or energy program for short- or long-term have been questioned with respect to their nuclear intentions.

However, up until the end of the Cold War, the number of countries that actually acquired nuclear weapons remained surprisingly small: Besides the permanent members of the UN Security Council, only Israel, India, and South Africa had built the bomb. Nonproliferation measures—such as the nuclear NonProliferation Treaty (NPT), nuclear safeguards implemented by the International Atomic Energy Agency (IAEA), and multilateral as well as national technology and export controls in combination with non-nuclear countries' self-restraint and nuclear powers' security guarantees and/or coercive diplomacies—contributed to keeping numbers low.

Furthermore, with the end of apartheid, South Africa abolished its nuclear arsenal. Belarus, Kazakhstan, and the Ukraine agreed to give up their nuclear weapons inherited from the disintegrating Soviet Union. For a short moment in history, during the early and mid-nineties, there was even some hope that nuclear disarmament and nuclear nonproliferation might jointly free the world from the danger of nuclear annihilation.

Today the picture is very different again. Proliferation has returned to the top of the list of threats to international security. Several factors contributed to this development. Nuclear weapon states did not reduce their nuclear arsenals as quickly as many non-nuclear weapon states expected them to do once the Cold War had ended. Some nuclear powers repeatedly talked about the necessity for nuclear modernization. The disintegration of the Soviet Union and Russia's weakness thereafter caused serious concerns about the Soviet successor states' capability to secure nuclear weapons, nuclear materials, technologies, and knowledge. After the 1991 Gulf War, international inspectors revealed a secret Iraqi nuclear weapon program which was formerly unknown and more advanced than expected. It existed despite all nonproliferation measures. In 1998, both India and Pakistan caught the world somewhat by surprise and tested nuclear weapons. Pakistan had to be added to the list of nuclear weapon states. Finally, after a long looming crisis of more than ten years, in 2003 North Korea became the first non-nuclear member state to leave the NPT and declare it had nuclear weapons.

Since 9/11 public awareness for proliferation risks has been growing rapidly. A whole new group of proliferation actors and recipients has been added to the picture: transnational non-state actors such as terrorists, organized crime members, religious extremists, and transnational companies. While some experts had these actors on their radar screens for many years, politicians and the wider public began to worry in the aftermath of the New York and Washington terror attacks. What if terrorists would use a nuclear weapon or a dirty bomb made from radioactive materials and conventional explosives in a major future terrorist attack?

Indeed, part of the new attention resulted from politicians, think tanks, and industries in the United States and elsewhere quickly joining efforts to turn terrorism—and especially terrorism through weapons of mass destruction—into a strong selling point for their products, services, and interests. They were hoping for a massive infusion of taxpayers' money into their respective budgets and areas of political influence. However, an illogical interest-induced hype can be taken as proof that the problem itself is no more than a hoax. Transnational non-state actors, such as terrorists, indeed might attempt to get access to nuclear materials, knowledge, or technology. If they consider building dirty, crude, or even elaborate nuclear explosives, the possibility that they might succeed creates a serious enough problem to take precautionary measures. As of today, the one-billion-dollar question is to what extent this general risk has already become a concrete or acute threat. However, no one has an honest and truly reliable answer.

With proliferation returning to the top of the international security agenda, proliferation risks resulting from all types of nuclear programs are getting additional attention again. The current debate about the Iranian nuclear program is a good example. Iran's program is mistrusted not only because Iran secretly imported nuclear technology and violated some of its obligations as a non-nuclear member of the NPT under the IAEA safeguards. Iran is also not trusted because of the world's experience with Iraq and North-Korea. The Iraqi example made it clear that a country could run and hide a military nuclear program from traditional IAEA-controls. North Korea may have even obtained nuclear weapons through a "civilian" nuclear program despite nonproliferation safeguards. Although North Korea was facing massive international suspicions as well as sanctions, the country succeeded in at least coming sufficiently close enough to developing a nuclear weapon to risk withdrawal from the NPT. Today, many nations are keen to prohibit Iran from becoming another North Korea. Even if the Iranian nuclear program as well as the country's intentions were entirely civilian, as Tehran claims, Iran would be mistrusted. "After North Korea," all new civilian nuclear programs consisting of more than light-water and light-water research reactors are likely to be met by a much higher level of skepticism. Iran is only the first country to face this new, emerging nonproliferation environment. Others are likely to follow.

This paper contains a short survey of the proliferation risks associated with the civilian use of nuclear energy. It looks at the major elements of the fuel cycle and their potential to play a role in proliferation. It takes a look at state and non-state actors and their capability to exploit proliferation risks of civilian nuclear installations for getting access to nuclear materials, nuclear technology, and nuclear know-how. It conducts a short survey of the major nonproliferation measures already in existence or under consideration. Finally it takes a short look at the future. What are the prospects for the civilian use of nuclear energy and what implications for future proliferation risks can be predicted?

1 Civilian nuclear installations – a quick overview

According to the IAEA, about 30 countries operate 441 commercial nuclear power plants.[1] They supply less than 5 percent of the world's entire energy, but as much as 16 percent of the world's electricity. The vast majority of all commercial power reactors are operated by countries in the industrialized world. The United States has 104 operational reactors, France 59, Japan 55, Russia 31, and the United Kingdom 23. Germany operates 18, Canada 17, and the Ukraine 15. A growing number of nuclear power plants is operated by developing and industrializing countries. South Korea has 20 operational nuclear power plants, India 15, China 9, and Argentina, Brazil, Mexico, Pakistan, and South Africa each operate 2. Iran has announced it will build 2 reactors. Most of the world's reactors are Pressurized Water Reactors (214), Pressurized Heavy-Water Reactors (40), Boiling Water Reactors (89), and Russian WWERs (53). A majority of the world's nuclear power plants use Low Enriched Uranium (LEU), containing 2–5 percent U-235 as fuel. Some, such as graphite-moderated or heavy-water reactors, utilize natural uranium. As of today, only a very few are fast breeders.

Most countries operating nuclear power plants do not operate a closed or a complete open fuel cycle.[2] Some do, especially those having (or having had) a nuclear weapon program, capability, or intention.

The uranium used as fuel in these reactors comes from two major sources. Slightly more than 50 percent comes from uranium mines, currently operational in 19 countries, producing between 40,000 and 50,000 tons of natural uranium per annum. The biggest suppliers are Canada and Australia, who jointly provide more than 50 percent of the newly-mined uranium. Other big suppliers include Kazakhstan, Niger, Russia, Namibia, and Uzbekistan. Iran recently became the latest country to mine uranium. By 2003, 46 percent of the global uranium supply for civilian reactors came from secondary sources such as re-enrichment of depleted uranium, reprocessing of spent fuel, and downgrading Highly Enriched Uranium (HEU). It is not clear whether such a high share of secondary source supplies can be maintained for long. The IAEA expects that the need for newly-supplied uranium or alternative fuel cycles will increase after 2015. The OECD, which expects an increased demand for newly-mined uranium for 2020, lists a total of forty-three countries known to have recoverable uranium resources. Exploration for uranium mining is conducted in a number of additional countries.

Uranium enrichment is achieved by different technologies, such as gaseous diffusion, gas centrifuges, electromagnetic isotope separation, and jet nozzle or aerodynamic separation.[3] All five traditional nuclear weapon states operate(d) enrichment facilities for commercial purposes and have operated such facilities for military purposes, too.[4] The latter is also true for Pakistan.[5] Argentina, Germany, the Netherlands, Japan, and South Africa operate commercial enrichment facilities. Laboratory research, pilot or smaller standby enrichment facilities exist

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[1] In this chapter IAEA figures are used. They are contained in different IAEA publications and online-databases which are not entirely consistent. These databases can be accessed under the links provided on http://www.iaea.org/programmes/a2/index.html.

[2] For the purposes of this paper, a closed fuel cycle is a fuel cycle in which nuclear fuel can be produced from natural uranium spent in a reactor, reprocessed, and turned into fuel again. An open fuel cycle is understood to be a once through fuel cycle. Used nuclear fuel is not reprocessed but put into storage.

[3] Some additional technologies, such as laser isotope separation technologies have been developed, but have not been commercially used.

[4] China, France, Great Britain, Russia, and the United States publicly announced that they do no longer enrich uranium for military purposes.

[5] India and Israel have experimental enrichment programs; however their nuclear weapons were plutonium based.

in a number of additional countries such as Australia, Brazil, South Korea, and, most recently and controversially, Iran. North Korea is suspected of having a military enrichment program.[6]

Once irradiated in reactors, spent fuel can be reprocessed in commercially-used facilities in Great Britain, France, Russia, and soon in a large facility in Japan[7]. Japan will become the first non-nuclear weapon state to operate a commercial reprocessing plant. Additional countries such as Germany operate(d) smaller scale experimental facilities. Military reprocessing facilities separating plutonium for nuclear weapons exist in additional countries, such as the nuclear weapon states of Israel, Pakistan, and North Korea. Several countries operating civilian nuclear power plants, for example Germany or the Netherlands, send their spent fuel for reprocessing to commercial plants outside of their own borders. The reactor plutonium separated there is either sent back or converted (elsewhere) into Mixed Oxide reactor fuel (MOX). It can also be stored.

Separated reactor plutonium is stored by a number of developed nations either on their own territory and/or on the territories of countries reprocessing spent fuel for them. Storage sites in non-nuclear countries are under safeguards as are MOX production facilities. Storage at reprocessing facilities in nuclear weapon states falls under safeguards only if the host country deliberately agreed to safeguards. Most developing countries operating nuclear power plants do not reprocess spent fuel. Instead, their spent fuel is in long-term storage or sent back to the country that supplied it. Spent fuel makes up for much of the reactor plutonium that currently exists. With no decision taken about what to do regarding the final disposition of highly radioactive waste, it is difficult to predict whether and which longer-term proliferation risks might result.

Belgium, France, and the United Kingdom are among those countries who can produce MOX reactor fuel. On the one hand, producing MOX allows the reduction of the stockpiles of separated reactor or military plutonium. On the other hand, it is under criticism for introducing additional plutonium into the fuel cycle. Several countries use or plan to use MOX to reduce their reactor plutonium stockpiles. Belgium, France, Germany, Sweden, and Switzerland are among them. India and potentially China plan to do. Japan plans to operate MOX-fuelled fast breeder reactors. Germany once planned for a large MOX-fuel production but has since dismantled both its pilot and its commercial MOX facilities.[8]

HEU-fuel is currently used in about 130 research reactors out of a global total of 270. Research reactors are located in 69 countries. HEU-fuel is at the core of proliferation concerns because it is relatively easy to handle at low risk. Of the spent fuel originating from research reactors about one-third is HEU. Substantial quantities are still located at decommissioned reactors. Less than half of all 382 decommissioned research reactors have been fully dismantled.

With a view to proliferation, the most risky elements of civilian nuclear fuel cycles are:

- technologies and facilities to enrich uranium
- HEU-fuel for research (or naval) reactors
- research reactors and nuclear power plants capable of producing plutonium

[6] Data on uranium enrichment facilities and their status are difficult to find and harmonize. The best collection of data available to the author is: Makhijani and Smith, Uranium Enrichment, October 15, 2004. Since enrichment facilities are of possible relevance to nuclear weapons programs, additional secret facilities might exist.

[7] Japan’s new reprocessing plant at Rokasho-mura is scheduled to become operational in July 2006. It will have a capacity to reprocess 800 tons of spent fuel per year. To reduce proliferation concerns, the plutonium separated will be turned into MOX fuel at the same facility.

[8] Attempts to export the MOX fabrication technology first to Russia and later to China were met by substantial public opposition and since given up.

- reprocessing plants allowing separation of plutonium and the technologies used in such facilities
- storage facilities for separated plutonium
- research as well as production facilities for the production of certain other materials useful for nuclear weapons, such as tritium, polonium-210, etc.

2 Proliferation risks

Two different groups of general proliferation risks inherent to civilian nuclear fuel cycles can be distinguished. The first group contains risks originating from a loss of control within a legitimate civilian nuclear program. Nuclear materials, nuclear technology or know-how can be stolen and transferred abroad to support a nuclear weapon program in another country. Abdul Q. Kahn's 1974 theft of uranium-enrichment centrifuge technology from Urenco in the Netherlands is one example; his network's activities to supply Iran, Libya, and North Korea with nuclear know-how, technology, and equipment indicate that a recipient country of proliferation can become a proliferator, too.[9] In general, what can be proliferated is nuclear materials, technology, and technological know-how as well as knowledgeable and trained personnel ("brain drain"). These risks can come into effect separately. They can also appear in combination with each other.

The second category of proliferation risks contains the same basic elements: nuclear materials, nuclear technology, know-how, and nuclear specialists. However, in this category a civilian nuclear program is used to support or is turned into a nuclear weapon program. A state decides to make use of the military nuclear option and uses both his indigenous and foreign sources of supply to be successful.

To develop a nuclear weapon capability, both state and non-state actors can opt for two different paths. They can try to build a uranium- or a plutonium-based weapon. In both cases they need a substantial amount of fissionable material. The IAEA considers 25 kg of High Enriched Uranium (HEU, containing 90 percent or more U-235) or 8 kg of plutonium-239 to be the reasonable minimum amounts from which a simple but working nuclear weapon can be built.[10]

HEU can be produced in different types of enrichment facilities. Meanwhile centrifuge enrichment has become the most common way to conduct uranium enrichment. Plutonium is a by-product of irradiating nuclear fuel in different types of reactors. Depending on the reactor type and the time for which the nuclear fuel is irradiated, different amounts of weapons-grade plutonium-239 and/or reactor plutonium-240 can be produced. The plutonium needs to be separated from the irradiated reactor fuel in chemical reprocessing facilities before it can be used for building a nuclear weapon.

For the purposes of this paper, programs trying to build or explore options to build nuclear weapons can be distinguished into two categories. First, there are nuclear programs which had a military purpose from the outset. The United States, Britain, the Soviet Union, and China are examples. Second, there are programs which were started officially as civilian programs and to which the military aspect either was a secret addendum from the outset or added later.

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[9] However, from another perspective, Khan's case raises more new questions than it answers old ones. After his "confession," the Pakistani government pardoned Khan quickly and since has prohibited foreign experts (e.g., from the United States or from the IAEA) from questioning him. Earlier Khan seems to have had influential protection as well. A leading US intelligence official dealing with Khan was removed from his duties once he demanded urgent action against Khan. When the Netherlands wanted to arrest Khan during trips in the 1970s and 1980s, the CIA asked the Dutch government not to do so. As of 2005, the Khan affair shows some peculiar interim results: Libya overnight became a respectable member of the international community again for giving up its programs of weapons of mass destruction. However, Libya's nuclear program, which mainly or entirely consisted of Khan's supplies, came as a massive surprise even to experts who were staunch critics of Col. Ghaddafi. At the same time, Khan's confession that he supplied Iran and North Korea with enrichment technology resulted in massive suspicions about both countries.

[10] However, all experts agree that these amounts are far too large if an actor has access to the technology for building an advanced nuclear explosive device. For other options see below.

For many of these programs, it is difficult to know whether the military option has been "underlying " the civilian program from the beginning. Countries starting their nuclear programs officially as civilian ones include, for example, France, India, Israel, North Korea, and South Africa.

A second distinction can be made between countries seeking nuclear weapons by exploring the uranium and/or plutonium path. Countries which built nuclear weapons on both paths include the United States, the Soviet Union, the United Kingdom, China, and Pakistan. Countries which used only the plutonium path to successfully build their first nuclear weapons include Israel, India, and possibly North Korea. The only country which used uranium to successfully build a first nuclear weapon was South Africa.

Depending on which path through which countries seek a nuclear weapon capability, they will consider their needs for an indigenous fuel cycle. A country intending to build a uranium-based weapon will need an enrichment facility, but not necessarily a reprocessing and plutonium separation facility. It will also not necessarily look out for certain reactor types, such as heavy-water reactors better suited for producing weapons-grade plutonium. To the contrary, countries seeking a plutonium weapon would be more likely to look out for such reactors and a reprocessing capability, while at the same time not being that keen on also owning a uranium conversion or enrichment facility. Thus, countries seeking a nuclear weapon capability on only one of the two paths theoretically can limit themselves to operating an open fuel cycle, while countries trying to keep both options open will work on all elements of a closed fuel cycle.[11] Historically, many nations have tried to keep open both ways and therefore claimed a need to operate a fully-closed fuel cycle.

2.1 State actor risks

It was not many years after the United States launched the "Atoms for Peace" civilian nuclear cooperation program that concerns first arose over the "diffusion" of nuclear technology and the resulting risk that many nations might acquire nuclear weapons. In 1963, then US Secretary of Defense Robert McNamara estimated that eleven additional countries could acquire nuclear weapons within a decade and many more thereafter. When the NonProliferation Treaty was negotiated later in the 1960s, a constant argument in favor of this treaty was to talk about the need to avoid a world of twenty or thirty nuclear powers. In order to assess the risks of nuclear proliferation, it is useful to have a short look at successful nuclear weapon programs of the past.[12]

Israel's successful weapons program was based on a plutonium production-reactor and a reprocessing plant ostensibly provided for peaceful purposes by France without safeguards and under substantial secrecy. Norway had provided heavy water for peaceful purposes. The uranium reportedly came from Argentina, Niger, South Africa, and others. About 200 tons was scheduled to come from a Belgian ship from which it disappeared in 1968 while the ship was at sea. Notably, Israel represents the single case known in which the supply of uranium was a major problem.

India produced the plutonium for its 1974 "peaceful nuclear explosion" in a Canadian-designed research reactor supplied under a 1956 agreement with no safeguards required. In-

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[11] These fuel cycle facilities do not necessarily need to be of "commercial size." If time allows, a research reactor is sufficient to produce enough plutonium for nuclear weapons as the case of India's first nuclear explosive indicates. In a similar way, pilot plant size enrichment or reprocessing facilities can be sufficient.

[12] The five nuclear weapon states are excluded from this review. For more detailed information on national nuclear programs see http://www.globalsecurity.org/wmd/world/index.html and http://www.nti.org/e_research/profiles/index.html.

dia's reprocessing technology is based on the US-PUREX technology, declassified under the "Atoms for Peace" program and conducted in a plant designed in part by a US company. India's heavy water initially also came from the US, while additional amounts were secretly acquired from Norway and other countries. India's nuclear energy and weapons programs haven't always been integrated.

South Africa initially had a civilian nuclear program to which a military one was later added. Much of the technology was indigenous with substantial secret outside help, especially from West Germany. HEU-enrichment in South Africa was based on a German technology (Becker nozzle process) officially supplied for the civilian nuclear energy program. The South African nuclear program resulted in a uranium weapon.

Pakistan successfully worked on uranium weapons after having failed to obtain a reprocessing plant from France. The centrifuge technology used for enrichment had been stolen from the Netherlands, where Abdul Q. Khan, the father of the Pakistani bomb, had worked for the Urenco enrichment plant at Almelo. In addition, Pakistan secretly acquired nuclear technology from China, probably including the design for a nuclear weapon. Pakistan is believed to have also produced plutonium in an unsafeguarded Chinese-supplied reactor and believed to have possibly tested a plutonium-based weapon in 1998.

North Korea has claimed since early 2005 that it has built nuclear weapons. Two years before, in 2003, it became the first and only country to withdraw from the NPT.[13] The country's nuclear program goes back to the 1950s, when North Korea cooperated with the Soviet Union and received their first small research reactor plus additional nuclear technology in the 1960s. Later the reactor was enlarged using North Korean technology. After a failed attempt to enlist Chinese nuclear support, North Korea began to acquire reprocessing technology from the Soviet Union in the 1970s and to develop indigenous nuclear technology for uranium processing. In the early 1980s uranium milling facilities, a fuel-rod fabrication facility, research and development facilities and a 5 MW research reactor were added. During these years, North Korea considered the acquisition of gas-graphite moderated or light-water reactors for electricity production. While North Korea entered a trilateral safeguard agreement with the IAEA and Russia for the Russian-supplied reactor in 1977, it joined the NPT no earlier than 1985. A safeguard agreement was not concluded before 1992. During the IAEA's initial inspections, inconsistencies about North Korean reprocessing activities came to light. When the IAEA asked the UN Security Council for the authority to conduct a special ad hoc inspection, North Korea announced its intention to withdraw from the NPT in 1993, only to "suspend" this decision after intense negotiations with the United States one day before the end of the ninety-day advance notice period. After that, safeguard inspections were allowed for the ongoing nuclear program but not for verifying the program's past. When the reactor core of the 5 MW reactor was burned up in the spring of 1994, North Korea began to remove the fuel rods without IAEA supervision in a manner which compromised the IAEA's ability to reconstruct the reactor's history. The resulting new crisis was defused by a Framework Agreement negotiated by former US President Jimmy Carter who, in October 1994, talked North Korea into accepting an IAEA-verified freeze of reactor operations and continued NPT membership in return

[13] North Korea's real nuclear status is not clear. In the second half of the 1990s, some Western intelligence sources estimated that North Korea might have one or two nuclear weapons. These estimates were based on the amount of weapons-grade nuclear materials North Korea could have theoretically produced. Meanwhile, based on a similar methodology it is estimated that North Korea could have built up to eight weapons. However, today Western intelligence sources doubt North Korean claims that the country already owns nuclear weapons. They assume that North Korea uses this claim to strengthen its position in the six-party talks over its nuclear program. North Korea's status in respect to the NPT is unclear as well. Several countries claim that North Korea did not leave the treaty since it did direct its withdrawal notice to the United Nations, but not the depositories of the treaty. Finally, the six-nation talks have since reached an interim agreement, under which, if implemented, North Korea again would become a non-nuclear member of the NPT.

for the supply of two light-water reactors and deliveries of heavy oil for electricity production. This agreement successfully froze the North Korean program for almost a decade. However, when the United States, under President George W. Bush, claimed in 2002 that North Korea had a secret uranium enrichment program and stopped the heavy oil deliveries, North Korea retaliated by lifting the freeze on its nuclear facilities, ending IAEA monitoring, and again announced its withdrawal from the NPT. North Korea now claims to have built nuclear weapons which are plutonium-based. It is still unclear whether a uranium enrichment program exists in North Korea. No reliable judgement is possible about when North Korea's military nuclear intentions began.

Having reviewed the countries that actually built nuclear weapons, a second look can be taken at some of the countries known or suspected to have explored their military nuclear options.[14]

Argentina has had a civilian nuclear program for many years. The first research reactor was supplied by the United States in the 1950s. Later several more were built and two heavy-water power reactors were supplied by Germany and Canada. Thus there is a capability to produce plutonium. During the 1970s Argentina added a nuclear weapon program and built an unsafeguarded plutonium reprocessing plant, reportedly with help from Germany and Italy. In 1983 Argentina announced it had successfully enriched uranium in a secret, unsafeguarded facility at Pilcaniyeu, ostensibly for civilian purposes.[15] However, today all nuclear facilities in Argentina are under IAEA safeguards since the weapons program was abandoned in the late 1980s when a civilian government succeeded the military Junta, an agreement with Brazil was reached, and Argentina gave in to US pressure.

Brazil first tried to acquire centrifuge enrichment technology from Germany as early as in 1953, but was initially blocked by the United States. Washington later supplied the country with a research reactor, while Brazil continued enrichment research based on the German Becker nozzle technology. In 1975 a highly controversial agreement was concluded under which Germany would have supplied Brazil with a full closed fuel cycle, consisting of several nuclear power plants, an enrichment facility, and a reprocessing plant for civilian purposes. While the deal was later substantially scaled back under US pressure, Brazil secretly engaged in an unsafeguarded parallel military program, with the army being responsible for the plutonium path and the navy pursuing uranium enrichment. Both used personnel trained in the civilian program and are believed to have used technology supplied for the civilian program in unsafeguarded enrichment and reprocessing facilities. Brazil's military nuclear program was ended in parallel with Argentina's. Brazil joined the NPT in the 1990s. It continues to operate nuclear power plants.

Taiwan received a heavy-water reactor from Canada along with heavy water and some separated plutonium from the United States for civilian and research purposes. Reprocessing technology was coming from France and also sought in the United States, West Germany, and other countries. When IAEA and US inspections in the 1970s suggested that Taiwan intended to divert material from its safeguarded facilities to a secret military facility next door, the United States successfully pressured Taiwan to abandon the military program, to dismantle its reprocessing facility, and then sent the separated plutonium to the United States. However, by 1987 Taiwan constructed new hot cells and only after intense US pressure, the program was stopped again.

South Korea began a secret nuclear weapon program when it began to construct its first nuclear power plants in the early 1970s. When the United States threatened to withdraw its mili-

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[14] Japan and several European countries (e.g., Germany) have been deliberately eliminated from this survey, since their technological basis is sufficiently developed enough to allow for building nuclear weapons if they decided to do so. Libya is not covered because it no longer or never seriously tried to build a nuclear fuel cycle.
[15] None of the Argentinean power reactors require enriched uranium.

tary support for South Korea, Seoul agreed to end the program and to join the NPT in 1975. Since the 1980s, South Korea has launched several attempts to initiate a reprocessing program but has backed off when pressured by the United States. The 1991 denuclearization agreement with North Korea requires Seoul to refrain from uranium enrichment and reprocessing. However, in 2004 South Korea informed the IAEA about some previously unknown plutonium related experiments and thus is currently under special investigation.

Iran's nuclear program also goes back to the 1950s. In 1974 the Shah developed a plan to have 23,000 MW of nuclear generated electricity installed by 1995. His plan also foresaw the construction of uranium enrichment facilities[16] as well as a reprocessing plant. He negotiated the construction of several nuclear power plants individually with West Germany, France, and the United States. In the end, only two German-supplied reactors were contracted. The Iranian revolution and the 1980 to 1988 Iran-Iraq War brought the Iranian nuclear program to standstill. Nuclear research only continued through some technological assistance from China. Finally, in 1994 Iran succeeded in engaging Russia as its new nuclear supplier. Russia was willing to finish the German-designed reactors at Busheher, provide nuclear fuel, and to possibly also help with uranium enrichment. Under pressure from the United States, Russia finally agreed to limit its support to reactor construction, training for nuclear specialists, and supplying nuclear fuel which must be returned to Russia after it is spent. By 2002 and 2003, exiled Iranians began to claim that Iran was secretly building a substantial nuclear infrastructure not yet declared to the IAEA. When the IAEA started to verify these claims, it could confirm several.[17] It also detected that Iran had not declared the import of a small quantity of nuclear materials imported about fifteen years ago. In addition, inconsistencies with respect to Iran's declarations about past nuclear activities needed to be clarified. The newly-detected components of the Iranian nuclear program included uranium conversion and enrichment facilities, for which clandestine technology imports were discovered. In addition, Iran is building a heavy-water plant and plans to build a heavy-water research reactor and a fuel rod production facility.

Since the end of 2003, Iran and the European Union 3 (France, Germany, and the United Kingdom) have been trying to negotiate a solution. The Europeans are seeking first a freeze and finally an end to all Iranian activities which could help a nuclear weapon program, i.e., all enrichment and heavy-water-related activities, as well as a binding commitment that Iran will not pursue reprocessing technologies or ever leave the NPT. Iran insists that it is legally entitled to run an open fuel cycle for civilian purposes. Indeed, none of the components of the current Iranian nuclear program is illegal under the NPT. Thus, the negotiations can only aim at talking Iran into deliberately refraining from exercising its right as a deliberate and confidence-building measure. As the present paper is being written, these negotiations have developed into an arm-twisting exercise similar to the United States-North Korean (and later six-nations) talks.

Based on these experiences from successful nuclear weapon programs as well as from attempts to use civilian nuclear programs for military purposes, several conclusions can be drawn.

- First, today's proliferation risks indeed concentrate on the technologies mentioned at the end of chapter 2: uranium enrichment, reprocessing and plutonium separation, plutonium production, and HEU-fueled (research) reactors.

[16] Two uranium enrichment facilities were offered to Persia by Helmut Schmidt, West Germany's chancellor, in 1975. Cf. Klaus Wiegrefe, *Das Zerwürfnis* (Berlin: 2005) 79.
[17] Technically, the newly detected installations did not represent a violation of Iran's existing commitments toward the IAEA. Iran could have met its legal obligations by informing the IAEA about these installations at a later point in time.

- Second, civilian nuclear programs played a role in proliferation both as a cover up and as support to military programs. They make it difficult to judge a country's intentions.
- Third, international safeguards and export controls developed in the 1960s and 1970s nowadays seem to be insufficient to guarantee against breakout-options toward a military nuclear program. At the same time, it has to be recognized that a substantial number of unsafeguarded facilities that played a role in military nuclear programs were built at times when no legally binding requirement for safeguards existed, and supplier countries often did not insist on safeguards in order to not endanger business opportunities.
- Fourth, over time, countries that are engaged in nuclear activities, whether civilian or military, gain experienced personnel and technological skills which allow them to rely more on indigenous capabilities and less on foreign supplies. General technological progress contributes to this development as more and more countries can produce nuclear related equipment to standards that only industrialized countries could meet in earlier decades.
- Fifth, the concept of limiting the proliferation of nuclear technology for military purposes while promoting the civilian use of nuclear energy is in a deepening crisis.

2.2 Non-state actor risks

To experts, non-state actors became a major proliferation and security concern as early as in the late 1960s. Once the United States had completed the "Nth country" experiment, experts knew that it was possible to build a crude nuclear weapon based on non-classified information available in the public domain.[18] By 1975 a CIA research study stated: "The possibility of terrorists getting hold of nuclear weapons poses the most severe limitation on political efforts to manage proliferation. This is the most puzzling and extreme aspect of the potential diversification of nuclear actors. The same increasing availability of nuclear materials and technology which made nuclear explosives accessible to developing states can also be expected sooner or later to bring them within the reach of terrorist groups. (. . .) Because nuclear terrorists would, by definition, operate outside of official governmental processes, they are largely immune to international political controls. IAEA safeguards, for example, do not encompass provisions against terrorist removal of materials from a reactor complex."[19] Since the mid-1980s, and even more since the disintegration of the Soviet Union, experts had begun to worry in public. While the Soviet Union's huge nuclear infrastructure fell apart, arms-control and nonproliferation experts became more concerned than ever before that massive proliferation risks might result. While the former authoritarian Soviet system had kept its nuclear materials, secrets, and technicians under close control, its safety and security measures against proliferation (consisting of closed cities, rigid travel restrictions, and military as well as KGB control and surveillance) were unlikely to continue to be effective for any likely course of events in the future. Beginning in 1991 substantial attention was given to risks resulting from the possibility that nuclear materials, technologies, or even warheads might fall into the hands of either terrorists or organized crime members.

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[18] University of California, Lawrence Radiation Laboratory, Summary Report of the Nth Country Experiment, UCLR 50249, Livermore, CA, March 1967 (original classification: SECRET, partially released under the FOIA, January 4, 1995).

[19] Central Intelligence Agency, Managing Nuclear Proliferation, p.29.

Nuclear weapons in terrorist hands: Theoretically terrorists or organized crime members could obtain a nuclear weapon by either building or buying one. If they wanted to build one, they could try to produce, buy, or steal the nuclear materials necessary. If they tried to produce the materials, they would face the same problems as a state trying to go nuclear. Since non-state actors are not states, they would need a state to host them and the necessary infrastructure either intentionally or because the state could not control part of its territory. There are many obstacles on this path. Thus, for the time being, the option that terrorist groups could try to produce a nuclear bomb from materials which they produced themselves is rather remote. Even if a terrorist group could obtain the necessary fissile nuclear material by buying or stealing it, they would still need a weapons design, working precision fuses, and several other components difficult to get hold of. Despite the results of the Nth country experiment, it seems unlikely that a terrorist group could master these problems easily or quickly. If so, terrorists would most likely succeed if they cooperated with a state that had either nuclear weapons or nuclear weapon materials. Access to nuclear know-how and cooperation with well-trained nuclear personnel could also ease the task for terrorist groups. However, in the case of a nuclear weapon state showing the will to cooperate with a terrorist organization, the most logical question would be: Why should that state not be willing to hand over a complete weapon? The most probable supplier might be Pakistan. However, from all we know about Pakistani official and unofficial—as well as the Khan network's—contacts with either Al Qaida or the Taliban, the material gap between the evidence found and a working nuclear weapon still seems to be large.

Dirty bombs in terrorist hands: A scenario in which terrorists or organized crime members would build and use a dirty nuclear bomb is more likely. A dirty bomb consists of some radioactive material which is spread by exploding a conventional explosive device. No chain reaction is involved. One could imagine a conventional car bomb with a few dozen or hundred grams of a radioactive substance included. The main effect of a dirty bomb would be psychological. A US "war game" analyzing the worst-case effects of a rather large two-ton dirty bomb exploded in central Washington, DC, concluded that an area the size of one block might suffer severe and possibly permanent damage.

However, a major obstacle to building such a weapon results from the difficulties in handling the radioactive material involved. Since the effect of such a weapon results from the radioactivity and/or toxicity of the material used and not from a nuclear explosion, the radioactive material to be used presents an enormous risk to those building, handling, and employing the weapon. This is probably among the main reasons why no dirty nuclear weapon has yet been used.

Whether radioactive materials from one of the elements of a civilian nuclear fuel cycle would be the nuclear material of choice for building a dirty bomb is doubtful. There is a wide range of other nuclear materials much easier to access which could fulfil the requirements of a dirty bomb as good or even better than LEU, HEU, or even reactor plutonium. For example, HEU stolen from a research reactor—which represents one of the biggest security concerns these days—surely is not the ideal material for such a weapon. Radioactive materials from other contexts—such as research institutes, hospitals, or industrial production processes—are easier to access and often better fit such purposes (e.g., cobald-60, strontium-90, americium-241, or even the rare californium-252). Radioactive waste from some elements of the fuel cycle might find its way into a dirty bomb.

Radioactive materials in the hands of non-state actors: Radioactive materials themselves can pose a security risk, if in the hands of non-state actors such as terrorists or organized crime members. However, unless these materials are turned into a dirty bomb, their effect can be only local or directed against a limited number of persons. A few cases are known in which radioactive materials have been used to kill or hurt individuals. The nuclear materials likely to be used for such purposes in most cases will not come from civilian nuclear fuel cycle installations.

Nuclear materials smuggling: Since the disintegration of the Soviet Union, a large number of nuclear smuggling incidents have been observed, reported, or intercepted. Traditional rogue traders, organized crime members, and terrorists, as well as intelligence services and police authorities all showed a strong interest. So did the media. Thus it became difficult to distinguish between real attempts to conduct illicit trafficking, sting operations, and cases which were simply misreported. Analyzing incidents reported by the media does not tell much about the relevance of nuclear smuggling for nuclear proliferation. A more reliable source for coming to such a judgement is the Illicit Trafficking Database, established by the IAEA in 1995.[20] This database contains both smuggling incidents and incidents in which orphan sources, i.e., uncontrolled nuclear materials were found. Over 650 incidents were officially confirmed to the agency for the years from 1993 to 2004. The largest number of incidents (over 60 percent) involved radioactive materials being non-fissionable, such as caesium-137, strontium-90, cobald-60, or americium-241. Most of these materials raise concerns about their possible use in criminal or terrorist operations, since they could be used in Radioactive Dispersal Devices or a dirty bomb. Another 30 percent of all incidents involved nuclear materials, such as natural uranium, depleted uranium, thorium, and LEU. Up until the end of 2004, the IAEA had accounted for sixty-three incidents involving LEU. Eighteen incidents involved nuclear weapon materials between 1993 and 2004. From a proliferation point they are the most significant incidents. Seven incidents involved plutonium, six of those in quantities of less than a gram to 10 grams. The seventh incident, involving more than 360 grams of plutonium, occurred at Munich Airport in August 1994 and involved both Russian authorities as well as German intelligence. Eleven incidents involved HEU in quantities of less than a gram up to more than 2.5 kilograms. In most of these incidents, samples for larger follow-up deals seem to have been seized. However, the IAEA data seems to confirm the analysis and trends in non-state actor activities presented above.

Non-state actors and fuel cycle safety: Terrorists indeed might pose severe risks to the security of civilian nuclear installations. No systematic study of these risks is known. Some spotlights have been directed at individual parts of the problem. The United States is known to have conducted fifty-seven simulated “red team” attacks on some of its reactors during the 1990s. Often security was proven to be inadequate. Out of the fifty-seven mock attacks—including the use of fake bombs—twenty-seven were described as showing severe vulnerabilities that could have resulted in reactor “core damage” and the release of radiation.[21] Greenpeace succeeded in successfully scaling the UK Sizewell nuclear power plant in 2003 without facing resistance.[22] Research reactors at universities have been described as another major problem. If security problems are severe in industrialized countries having the resources to invested in the security of critical infrastructure, even larger risks might exist in countries not having comparable resources. To the author’s knowledge, no similar reports are in the public domain documenting mock attacks and analyzing security at nuclear laboratories, enrichment plants, reprocessing facilities, or spent fuel (interim) storage sites. Substantial risks might exist that nuclear materials might be released or disappear.

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[20] The data in this paragraph can be found at: http://www.iaea.org/NewsCenter/Features/RadSources/Fact_Figures.html and under the links provided on that page.

[21] Union of Concerned Scientists, Backgrounder on Nuclear Reactor Security, Cambridge, MA: 2002.

[22] Greenpeace UK, Greenpeace Volunteers Get into ‘Top Security’ Nuclear Control Centre, press release, London, January 13, 2003; also: *Daily Mirror*, January 14, 2003.

2.3 Other proliferation risks to be considered

Nuclear weapons from civilian nuclear materials: As early as 1962, the US Department of Energy conducted an underground test with a nuclear weapon made from reactor plutonium. The test was successful. The event was not made public until 1977. Since then, it has been publicly known that, in principle, it is possible to build nuclear weapons from "civilian" or "reactor plutonium." A study conducted at Los Alamos National Laboratories concluded in 1990 that states or a terrorist group trying to use reactor-grade plutonium to build a nuclear weapon would face difficulties differing only in degree, but not in kind, from those they would face if they had access to weapons plutonium.[23]

Wartime loss of control over nuclear materials: The 2003 war against Iraq revealed another important proliferation risk: While US troops were occupying Iraq, they did not properly protect the main nuclear research facility in the country from being looted. IAEA seals at the installation were broken, nuclear materials were lost, and documents stolen. Meanwhile, the IAEA secured and safeguarded all materials it could recover.

Failing states and nuclear installations and materials: Given the experience with the disintegration of the former Soviet Union, failing states can present the international community with proliferation risks. There is no guarantee that all countries operating research reactors or even more elaborate civilian nuclear programs will never begin to fail or become a failed state and thus loose control over their nuclear installations or materials. While it is widely acknowledged that failing states are a security problem, it is much less well-known that they also might confront the world with proliferation risks.

New sources of nuclear related technology: Recent findings about the proliferation activities of Abdul Q. Khan's network[24] revealed another important proliferation concern for the future. Developing nations are becoming an additional source of proliferation-related technologies and equipment. Growing technological capabilities of industrializing nations will enable some of them to produce and provide relevant components for nuclear facilities such as enrichment or reprocessing plants. Some sophisticated centrifuge parts included in Khan's dealings had been produced in Malaysia—a country that does not even have a substantial nuclear program of its own.[25] This very fact rings an alarm bell in time. There is no longer a guarantee that the relevant products will always have to come from one of those countries currently cooperating in export-control regimes such as the Nuclear Suppliers Group or the Zangger Committee. In addition, Khan's case shows that countries having a nuclear weapon program can become a source of proliferation.

[23] U.S. Department of Energy, Nonproliferation and Arms Control Assessment of Weapons-Usable Fissile Material Storage and Excess Plutonium Disposition Alternatives, Washington, DC: 1997, 37–39; National Academy of Sciences, Management and Disposition of Excess Weapons Plutonium, Washington, DC: 1994, 32–33; also: Harmon W. Hubbard, Plutonium from Light Water Reactors as Nuclear Weapons Material, April 2003 (manuscript).

[24] These concerns are of relevance independently of whether Khan's activities originated from his own interests or were conducted as part of a controlled or sting operation.

[25] Malaysia operates a single 1 MW low power research reactor at the Malaysian Institute for Nuclear Technology Research and currently has no plans to use nuclear energy.

3 Instruments to control and contain proliferation

Nearly all instruments developed to contain nuclear proliferation have been designed to prohibit states from conducting illegal military nuclear programs. Most of them had to take into account that the civilian use of nuclear technology is legal. None could be designed in an open attempt to limit or even deny the civilian use of nuclear energy. This said, the instruments used to contain proliferation can be divided into several categories. Some are multilateral treaties intended to prohibit proliferation or increase the difficulties for states pursuing nuclear weapons. They are accompanied by safeguard and verification measures to ensure treaty compliance. In addition, there are multinational or national export-control arrangements designed to make it impossible or difficult for non-nuclear countries to obtain the materials, technology, or know-how necessary for building nuclear weapons. States being technological "Haves" joined each other to control the flow of technology to "Have Nots." A third category of initiatives aims at prohibiting proliferation from countries which have nuclear materials, technologies, and know-how, but who face difficulties in guaranteeing nonproliferation from their soil. Cooperative measures to ensure that proliferation does not occur are implemented with outside help. Finally, two new categories of measures have been added in recent years: Coercive measures to intercept technology transfers, and options for military counter-proliferation. The following section describes the strengths and weaknesses of some of the more important instruments developed. Because of the wide variety of nonproliferation instruments existing or under consideration, a complete or detailed survey cannot be conducted.

3.1 Major multilateral treaties with nonproliferation impact

Nonproliferation by treaty: The nuclear NonProliferation Treaty (NPT) has become the globe's cornerstone multilateral instrument of nuclear nonproliferation. Initialed by the first signatories on July 1, 1968, and entering into force in 1970, the treaty enjoys nearly universal membership today. Only Israel, India, and Pakistan never became members. North Korea withdrew from the Treaty in 2003.

The NPT commits it non-nuclear members "not to receive the transfer from any transfer or whatsoever of nuclear weapons or other nuclear explosive devices or of control over such weapons or explosive devices directly, or indirectly; not to manufacture or otherwise acquire nuclear weapons or other nuclear explosive devices; and not to seek or receive any assistant in the manufacture of nuclear weapons or other nuclear explosive devices," (Art. 2). Vice versa, nuclear weapon states commit themselves in Article 1 not to help non-nuclear states to circumvent the above commitment directly or indirectly. However, Article 4 ensures the non-nuclear weapon states that they are fully entitled to make civilian use of nuclear energy and can expect the transfer of related modern technologies from countries already in possession of them. Article 4 reads:

1. "Nothing in this Treaty shall be interpreted as affecting the inalienable right of all 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.
2. All the Parties to the Treaty undertake to facilitate, and have the right to participate in, the fullest possible exchange of equipment, materials and scientific and technological information for the peaceful uses of nuclear energy. Parties to the Treaty in a position to do so shall also cooperate in contributing alone or together with other States or international organizations to the further development of the applications of nuclear en-

ergy for peaceful purposes, especially in the territories of non-nuclear-weapon States Party to the Treaty, with due consideration for the needs of the developing areas of the world."

While the treaty makes an unusual distinction between states which for the time being are entitled to own nuclear weapons (Haves) and states who are not (Have Nots), it also contains two provisions signaling that this distinction was and is not intended to exist forever: The first provision is contained in Article 6 and commits the nuclear weapon states "to pursue negotiations in good faith on effective measures relating to cessation of the nuclear arms race at an early date and to nuclear disarmament, and on a treaty on general and complete disarmament under strict and effective international control." The second provision is contained in Article 10 and reads: "Twenty-five years after the entry into force of the Treaty, a conference shall be convened to decide whether the Treaty shall continue in force indefinitely, or shall be extended for an additional fixed period or periods."

In 1995, twenty-five years after the NPT was put into force, a review and extension conference was held which, without a vote, agreed to extend the treaty unconditionally and indefinitely. This decision was made possible since a "Principles and Objectives" document was agreed upon at the same conference and further developed into thirteen practical steps during the next Review Conference in 2000, which for the first time contained concrete aims and a work plan for strengthening both nonproliferation and disarmament by the nuclear weapon states. Decisions taken in 1995 and 2000 thus reflected the same deal which was underlying the treaty itself: Nonproliferation can be strengthened if disarmament with the goal of final elimination of nuclear weapons makes progress, too. Progress on achieving the 1995 and 2000 commitments was slower than expected by most NPT members. By the time of the next Review Conference in May 2005, the underlying basic deal for the treaty and its extension was no longer accepted by all members. Under George W. Bush, the US government no longer feels committed to the "Principles and Objectives" and the thirteen-steps process. The new US administration concentrated on unilateral rather than multilateral initiatives to strengthen nonproliferation and did not accept any disarmament-related commitments for the nuclear weapon states.

However, the treaty itself has several built-in weaknesses relevant for proliferation. In short, they are:

- The treaty distinguishes between "Haves" and "Have Nots." This distinction is unique in international law, which normally treats all sovereign nations as equal. Since the US government withdrew its support of the "principles and objectives process," many non-nuclear member states have become increasingly critical of the nuclear powers' lack of emphasis to disarm. This conflict has the potential of letting the NPT erode in the future.
- In Article 4, the treaty entitles all non-nuclear members to fully engage in civilian use of nuclear technologies. It commits nations in possession of such technologies to allow access to these technologies by nations who do not possess them, but who want to use them for civilian purposes, such as electricity production. Under the NPT, it is legal for a non-nuclear state to operate a fully closed nuclear fuel cycle. This includes the right to run a number of facilities with a high potential for proliferation. Proposals for additional safeguards and export restrictions of these elements of the fuel cycle—often made or supported by the nuclear weapon states—increase the divide mentioned above.
- Israel, India, and Pakistan never signed the NPT, but acquired nuclear weapons. Since the treaty does not allow for new nuclear weapon states to become members, a deci-

sion to give up nuclear weapons would be a precondition for any of these states to join the treaty. However, this is unlikely to happen. Many non-nuclear members to the NPT therefore are becoming increasingly critical about these additional nuclear weapon states being tolerated as de facto nuclear weapon states outside the treaty.

- Israel presents a difficult case of its own. Israel follows a policy of deliberate ambiguity about its nuclear weapon potential. While it is official policy that Israel would not be the first to use nuclear weapons in the region, all Israeli governments since the 1970s have indicated that they do possess an operational nuclear weapon posture, which they could use on very short notice if required. Ever since the illegal preemptive Israeli attack in 1981 on the Iraqi nuclear power plant under construction in Osirak, the Begin doctrine has caused additional problems in the Middle East. Before 1981, the Arab and Islamic world's main point of criticism was that Western nations secretly accepted or even helped the Israeli nuclear program. Now, under the Begin doctrine, Israel retains the right to attack nuclear-related targets in any Arab or Islamic country in the region which is under suspicion of building nuclear weapons. The Osirak incident, however, can be read as implying that Israel also denies its Arab and Islamic neighbors the right to use nuclear power to produce electricity. Since all of the Muslim countries potentially affected by such an interpretation are non-nuclear members of the NPT, they perceive Israel—a non-member of the NPT—as depriving them from their "inalienable right" guaranteed under Article 4 of the NPT.

CTBT: The Comprehensive Test Ban Treaty (CTBT) is a second multilateral treaty potentially having an impact on proliferation. As early as in February 1963, former US Secretary of Defense Robert McNamara argued in a memorandum for President John F. Kennedy: "A comprehensive test ban agreed to by the US, USSR and UK will work in the direction of slowing diffusion. It is probably not an exaggeration to say that it is a necessary, but not sufficient condition for keeping the number of nuclear countries small."[26] However it wasn't until after the Cold War before such a treaty was concluded. In 1996 the Comprehensive Test Ban Treaty was offered for signature. Since then, more than 100 countries have signed the ban. However, it still remains unclear whether the CTBT ever will enter into force. All forty-four countries having a civilian or military nuclear program need to ratify the treaty before they can enter into force and thus "slow diffusion." Eleven countries have not done so yet; some did not even sign the treaty. While several nations are unlikely to do so in the foreseeable future, the United States—under the current administration—is even considering withdrawing its signature.

A CTBT in force would make an important contribution to nonproliferation: Countries building a nuclear weapon would not know for certain whether their nuclear weapon design is going to work properly. While this hurdle may not have a huge impact on the reliability of nuclear weapon designs based on HEU or plutonium,[27] it might have a much higher impact on designs based on civilian nuclear materials, such as reactor plutonium.

FMCT: The Fissile Material Cut-Off Treaty is a proposal to strengthen nonproliferation by concluding a multilateral treaty. Negotiations at the UN Conference on Disarmament have not yet begun although the idea has been around for many years. The treaty would ban the production of new fissile materials for nuclear weapons. It would be concluded by both nuclear and non-nuclear members. In nuclear weapon states it would limit the amount of fissile material available for building weapons. In non-nuclear countries it would function as an additional safeguard-instrument against proliferation. Together with existing programs to elimi-

[26] Secretary of Defense, Memorandum for the President, Subject: The Diffusion of Nuclear Weapons with and without a Test Ban Agreement, Washington, DC: February 12, 1963, 3 (original classification: SECRET).
[27] Countries testing such designs succeeded in most cases with the first attempt.

nate excess fissile materials—such as US-Russian efforts to blend down 500 tons of Russian excess weapons-grade HEU to reactor-grade LEU—it would help to reduce the amount of weapons-grade materials available.

Nuclear Weapons Free Zone Treaties: For a number of regions, Nuclear Weapons Free Zone Treaties (NWFZ) have been established in accordance with Article 7 of the NPT. They constitute both a confidence-building measure against the possible proliferation of nuclear weapons and an additional legally binding hurdle against nuclear proliferation. In a mutually legal-binding manner, parties within an NWFZ state assure each other to not acquire nuclear weapons. In addition, existing NWFZ are backed up by politically-binding Negative Security Assurances provided by the Nuclear Weapon States. Established zones of the NWFZ include:

- the Pacific Nuclear Weapons Free Zone established through the Treaty of Roratonga
- the Latin American and Caribbean Nuclear Weapons Free Zone established through the Treaty of Tlatleloco
- the African Nuclear Weapons Free Zone, established through the Treaty of Pelindaba

Additional regional NWFZs are under negotiation or consideration, for example:

- the Middle East, originating from a proposal made in 1974 by the Shah of Persia; it is still mostly an idea. However, during 2004, IAEA Secretary General al-Baradei obtained an agreement from all major states in the region, including Israel, to hold a regional seminar on the issue during 2005;
- Central Asia;
- North East Asia.

The nonproliferation effect of NWFZs is limited. However they are a confidence-building measure and provide members with a mutual assurance that they will not seek nuclear weapons.

3.2 Nonproliferation through safeguards

The existence of international safeguards against proliferation is based on Article 3, paragraph 1 of the NPT. The idea is that non-nuclear states will only be entitled to receive nuclear materials and technology if they allow the IAEA to verify that their nuclear programs are peaceful only. Thus the main focus of safeguards is to prohibit nuclear materials from a civilian nuclear fuel cycle being diverted for military purposes.

The safeguard system existing today was formulated in two major phases. During a first phase, a framework for the implementation of safeguard agreements and detailed guidelines for the conduct of IAEA inspections were negotiated. Agreement on this document, Information Circular 153 (INCIRC 153), was reached in 1972. Based on this document, safeguard agreements between the IAEA and individual states were concluded and published. For example, INFCIRC 214 contains the safeguard agreement between Iran and the IAEA. Safeguard agreements contain detailed rules about when non-nuclear states are obliged to provide the IAEA with certain information about their nuclear facilities, materials, and programs. They entitle the IAEA to verify the correctness of the information received via inspections inside the member state. In the case of the IAEA judging that a country fully cooperated with the IAEA and only worked on civilian nuclear projects, this country can continue to receive nuclear materials, technology, etc. If the IAEA judges that there are doubts and/or open questions about a country's nuclear program, it is entitled to begin additional special investigations with the purpose of either clearing the country of existing suspicions or reporting violations of obligations to the UN Security Council for a decision on further action. In early 2005, comprehensive safeguard agreements between the IAEA and 166 countries were in force.

In the aftermath of the Gulf War of 1991, IAEA inspectors revealed that non-nuclear Iraq had been running a secret nuclear weapon program for many years. These IAEA inspectors had been granted additional inspection rights under a specific UN Security Council resolution after the end of the war. Their findings led to the conclusion that the existing safeguard agreements were insufficient in prohibiting a country from conducting a secret military nuclear program and that an additional and more intrusive safeguard agreement was necessary to cope with such challenges. By 1997 the IAEA member states had negotiated a voluntary "Model Additional Protocol" (INFCIRC 540) on extended safeguards. Countries accepting the protocol allow the IAEA to inspect undeclared facilities, to conduct additional short-notice inspections, and to carry out environmental sampling operations. It also commits countries to provide the IAEA with lots of additional information, such as declarations on all imports and exports listed on the Nuclear Suppliers Group trigger list (see below). As of 2005 the additional protocol is in force for sixty-five nations; another twenty-five have signed it.

The additional protocol is of specific value if a country is under suspicion of violating its commitments under the NPT and the safeguard agreement. Therefore, when the Islamic Republic of Iran came under such suspicion in 2003, the IAEA and many member states were very keen about the fact that Iran had signed the additional protocol, thus granting the IAEA the additional authorities contained within. In November 2003 Iran signed the protocol. However, while the Iranian government has been behaving as though the protocol were in force, the Iranian parliament has not yet ratified it.

The existing safeguards are intended to prohibit the diversion of civilian nuclear capabilities to military purposes in non-nuclear states. They neither deal with military installations in nuclear weapon states nor with civilian nuclear installations in these countries, unless the nuclear weapon states deliberately agree to place certain installations or materials under IAEA safeguards. Safeguards are also not applied to nuclear installations in states which are not members of the NPT, unless these states deliberately agree to place some installations under safeguards.

Although IAEA inspections again and again have been criticized for being costly, lengthy, and either inefficient or insufficient, they are obviously much better than their critics pretend. In Iraq the IAEA (and UNMOVIC) inspectors revealed the Iraqi nuclear program and concluded correctly in 2003 that it had not been reactivated.

Current suggestions to strengthen IAEA safeguards include calls to make the additional protocol universal and mandatory for non-nuclear states seeking nuclear-related imports. Several Western states suggested that goods listed by the Nuclear Suppliers group should only be exported to countries where the additional protocol is in force.

However, inspections will reach their natural limits if inspectors are not allowed to do what they are supposed to do or if they are asked to verify details outside of their authority. The same is true if they are not given the time necessary to come to a careful and fair judgement. Inspectors, just like any multilateral institution, can only do what the member states let them do. They cannot produce proof that a nuclear weapon program or part of such a program definitely does not exist. They require the political cooperation of both the state party being inspected as well as the state parties asking for inspections. To be suspicious is part of their job, not a signal for a lack of impartiality. It is important that their (interim) results are neither politicized nor published before the inspected country has had a chance to comment on the results or correct errors.[28]

IAEA safeguards have to be seen in conjunction with export-control measures, both national and multilateral, created to prohibit proliferation.

3.3 Nonproliferation by export controls

Multilateral export-control measures used to supplement safeguards and prohibit proliferation have exist since the early 1970s. They are based on Article 3, paragraph 2 of the NPT, which commits all member states to supply nuclear materials or technologies only if they are subject to safeguards in the recipient country.

Those states capable of supplying nuclear technology began to hold informal meetings in 1971. Later, their forum became known as the Zangger Committee. They developed a "trigger list" of nuclear items that require safeguarding and three conditions under which a country could receive such items: The recipient must have a safeguard agreement in place, use all his imports for peaceful purposes, and apply these two conditions to potential recipients of re-exports.

Supplemental to the NPT and the Zangger Committee, forty-four nations with the capability of exporting nuclear materials or technology form the London Nuclear Suppliers Group (NSG), which has existed since 1975. The group agreed on an extensive trigger list of nuclear materials, technologies, and equipment that should be subject to national export controls as well as on a list of relevant dual-use technologies. These lists are updated from time to time in order to keep track of modern technologies. Both lists are part of the NSG guidelines, which are politically but not legally binding. However, as member states are committed to including the items and goods into their national export-control system, they become legally binding.

In recent years some new initiatives have been launched to tighten control over nuclear technology supplies. Based on a US proposal, the June 2004 G-8 Summit agreed on an extendable one-year moratorium on new transfers of uranium enrichment and reprocessing technologies to states not already in possession of such technologies.

Many non-nuclear member states, namely developing nations, have been either skeptical or openly critical about the relationship between safeguards and export controls in general, and specifically about attempts to make nuclear-related exports subject to the recipient state meeting additional conditions. They feel these rules to have a potential of being applied in a discriminatory manner while prohibiting legitimate access to modern nuclear technology as assured under Article 4 of the NPT. Over the last several years, the criticism has become both louder and more outspoken.

Alternative and less discriminatory approaches to safeguard and export controls under discussion include options to multilateralize fuel cycle operations such as uranium enrichment or reprocessing facilities: Multilateral fuel cycle facilities are an old idea for strengthening nonproliferation. If several countries use the same facility, it is less likely that a diversion of nuclear materials or breakout attempts would go undetected. The participating nations control each other. An international expert group on multilateral fuel cycle operations presented a report to IAEA Director General al Baradei in early 2005.

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[28] Iran has correctly made this case. IAEA (interim) findings and reports on the investigation of Iran's compliance with its safeguard obligations have been repeatedly reported in news media in a politically-biased form before Iran could correct even factual errors.

3.4 Nonproliferation by cooperation

The disintegration of the former Soviet Union and consequential concerns about whether a Russia in crisis would be capable of retaining the necessary strict control over its huge nuclear complex resulted in a wide range of cooperative nonproliferation measures. Initially conducted mostly by the United States but meanwhile joined and co-financed by a wider range of nations, a wide range of cooperative activities has been developed. Many fall under or originate from the "Cooperative Threat Reduction" program, initiated in 1991 by US Senators Nunn and Lugar. A full survey would go beyond what is possible in this paper. However, some major examples shall be given:

- Various projects aim at a more centralized, safer, and physically more secure storage of nuclear materials and weapons in Russia. Others aim at securing the nuclear fuel of decommissioned nuclear powered submarines.
- A number of projects such as the International Science and Technology Center Program, the Nuclear Cities Initiative, the Russian Transition Initiative, and the Proliferation Prevention Initiative focus on creating employment for nuclear scientists in order to avoid a "brain drain," i.e., proliferation resulting from scientists seeking foreign employment.
- Several programs focus on strengthening border controls and export-control administrations in Soviet successor states.
- Again others are trying to cooperatively end fissile material production in Russia and reduce fissile material stockpiles in the country. Under the 1996 Trilateral Initiative, the United States, Russia, and the IAEA agreed to place some excess fissile material (both plutonium and uranium) under IAEA safeguards. In 1993 the United States agreed to buy 500 tons of Russian HEU which is downblended and used as fuel in US nuclear power plants. So far, less successful was the implementation of the "Plutonium Disposition Agreement" under which the United States and Russia agreed to convert thirty-four tons of weapons plutonium each into either MOX fuel or immobilize it by mixing it with nuclear waste.

Since 2002, the program has been expanded to become the G-8 "Global Partnership Against the Spread of Weapons and Materials of Mass Destruction." The G-8 member states committed themselves to spend $20 billion over a ten-year period on this initiative.

In May 2004 the "Global Threat Reduction Initiative" was initiated jointly by Russia, the United States, and the IAEA. This initiative aims at repatriating fissile materials originating from the United States and Russia from more than forty countries around the world. One of the major elements of the program is to eliminate HEU as reactor fuel in civilian nuclear programs. HEU-powered research reactors have become a major proliferation concern. Even before this initiative came into being, fissile materials from a number of countries such as Serbia, Bulgaria, and Kazakhstan have been evacuated to either the United States or Russia.

Some initiatives originating from US–Russia cooperative threat reduction are being multilateralized and applied to additional countries. Examples include:

- helping countries to set up effective proliferation-resistant export controls
- projects to create alternative employment for nuclear specialists and scientists (part of the EU proposals to Iran)

Discussions about weaknesses to safety and security in the former Soviet Union also contributed toward initiatives in the IAEA context aimed at increasing the security of civilian nuclear operations. Examples include:

- amending the 1980 Convention on the Physical Protection of Nuclear Materials agreed on in July 2005
- developing the 1997 Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management

3.5 Coercive non-proliferation and military counter-proliferation

Since the administration of George W. Bush came to power in the United States in 2001, unilateral measures to prohibit proliferation have been strengthened. Two forms are worth mentioning. In May 2003 the Proliferation Security Initiative was launched. It is a US-inspired and led initiative, which aims to create legitimacy for intercepting shipments of nuclear, biological, and chemical weapons, their delivery systems, and related materials during international transfer by ship or aircraft. The idea was met with skepticism from many countries because it was likely to be in violation of several international treaties which guaranteed unrestricted passage of aircraft and ships during international transfers. However, when the Bush administration reduced the initial scope of the initiative and lowered the threshold for foreign participation in order to meet other countries' legal requirements for participation, additional nations showed interest. More than fifty countries participated in 2005.

By use of force, military counterproliferation operations attempt to reverse or disrupt proliferation that has already occurred. They can be conducted as sabotage, via special operations forces, military strikes from air and sea, or even as military interventions into territory where proliferation may have occurred. In case of a non-state actor trying to build nuclear explosives, military counterproliferation operations would target the territory of the host state independently of whether this state is intentionally hosting the non-state actor or because of a lack of control over parts of its territory. Military counterproliferation operations can be conducted in a preventive or preemptive manner or in retaliation. In many cases they imply a severe violation of international law, since they are acts of aggression from a legal point of view. The United States has made such operations an integral part of its published national security strategy. Other major powers have indicated a certain willingness to consider such options as well.

Short of a full-scale military intervention, military counterproliferation operations are likely to be prepared in secret in order to increase both the surprise element and the chance for success. If possible, they might be conducted in secret as well. They might not even be made public after the fact. It is not in the public domain as to how many such operations have taken place in history. Most of the known operations were part of wartime operations, e.g., Allied World War II strikes at German-controlled nuclear facilities in Europe. Also publicly known were the Israeli attack on the Iraqi reactor in Osirak in 1981. Finally, the case for the 2003 war against Iraq was made by using counterproliferation as one major legitimation. However, as it turned out, there was no proliferation to be reverse.

Because of secrecy, it is difficult to judge the real impact of such operations in reversing or delaying nuclear programs. From what is known, the impact is minor and questionable at the least. In addition, it has to be weighed against the risks of failure, the violation of international law, and the possibility of a faulty proliferation assessment underlying such operations. Recent public discussions about a possible US and/or Israeli military counterproliferation operation against the Iranian nuclear program have shed some more light on the complexity, the obstacles to success, as well as the imponderabilities of such an operation.

4 A world in search of energy

Concerns are growing whether today's main sources of primary energy—oil and natural gas—will continue to meet growing demand in sufficient supply. Worldwide demand for energy is growing rapidly, mainly as a result of Asian countries quickly developing into industrialized societies. Taking over labor- and energy-intensive production processes—formerly located in the now deindustrializing Western world as a consequence of the forces unleashed by globalization—the demand for energy in Asia has increased rapidly. A sufficient supply of energy has become one of the core prerequisites for Asian development. However, neither oil nor gas are endless or can be provided in unlimited quantities at affordable prices and at any time and place. Sooner or later shortages are expected, due to the difference between demand and supply or regional conflicts. Thus searching for alternative and additional sources of energy has become a major trend in both Western and developing nations. Nuclear energy is one of the alternatives being looked at with increasing intensity.

The Western world is awash with studies claiming that it is possible to contain proliferation while at the same time exporting civilian nuclear technology.[29] However, the nonproliferation solutions offered for the future are about as promising as the nonproliferation initiatives promoted during the 1960s and 1970s. They are likely to be of similar effectiveness, too. They offer some time to buy before the first examples demonstrating their loopholes are detected. With non-state actors entering the field, nonproliferation measures developed to prohibit or regulate proliferation between states are likely to offer more loopholes than in the past. One major problem remains overlooked by those promoting nuclear energy technology exports despite proliferation and security concerns. One cannot have maximum proliferation resistance and maximum economic benefits from exporting civilian nuclear energy at the same time.

Despite various precautionary measures taken, nuclear proliferation will continue to be a problem for international security. With all likelihood, it is not exaggerated to state that it is impossible to make the civilian use of nuclear energy one-hundred-percent resistant to proliferation. What seems possible is to increase the hurdles for nuclear proliferation, i.e., to contain the problem. However, all measures proposed and possibly undertaken with the aim of containing the problem are likely to loose some of their effectiveness over time. Technological progress and increased access to technology will ease attempts to circumvent nonproliferation measures—old and new—sometime in the future, or even allow for proliferation to exploit entirely new technological paths.

Given these prospects, even under best-case conditions, one should expect proliferation risks to grow slowly as the number of nations using nuclear energy to produce electricity increases. With each nation joining the civilian nuclear club, there are additional places in which nuclear materials need to be safeguarded, additional scientists and experts with specialized training and knowledge which require employment, and additional locations with installations possibly vulnerable to terrorist attacks.

In the future, proliferation risks might increase for several reasons: First, uranium itself is a limited source of energy. World uranium resources will definitely run out. Making uranium a more sustainable source of energy requires making use of closed fuel cycles and thus technologies containing higher risks of proliferation such as reprocessing and separating plutonium. Secondly, one of the effects of globalization observed has been a weakening of the state authorities' monopoly over the legitimate use of force and violence (in German: *staatliches Gewaltmonopol*). This phenomenon is often discussed under the rubric of "failing" or already "failed states." Failing or failed states exist in increasing numbers. In such states, governments can no longer control parts of the territories they are supposed to rule. They can no

[29] To give just one example: The Atlantic Council, Proliferation and the Future of Nuclear Power, 2004.

longer guarantee security. If failing states host nuclear installations, no matter whether they are civilian or military, they will immediately become a major proliferation concern. The disintegration of the former Soviet Union made the world aware of many aspects characterizing such a situation. Can we be sure that Pakistan will never become a failing state or disintegrate? Thirdly, as the number of countries operating civilian nuclear facilities grows and technology transfer to these countries continues, the number of countries becoming "nuclear technology suppliers" will increase. The deindustrialization of the West and the industrialization of the South will become a severe test for today's ways to control, limit, or deny nuclear technology exports. Some of the potential future nuclear supplier states may have a different understanding of legitimate civilian use of nuclear technology than the traditional nuclear powers and their close allies. The challenge to nuclear-related export-control systems will be substantial. Once such suppliers begin competing for market shares it is entirely possible that industries in Western nations will make an old and dangerous argument again, which helped to fuel nuclear proliferation during earlier decades: "If we don't sell it, they will. It's better we sell."

About twenty-five years ago, a SIPRI study[30] on proliferation risks of nuclear energy concluded that a once through fuel cycle based on multilateral enrichment and fuel fabrication facilities might be the most proliferation-resistant way to think about the future use of nuclear energy. The study urged to energetically use the two or three decades won by the NPT and other nonproliferation measures which would slow down the process of proliferation to develop such a resistant fuel cycle. Since then, little practical progress has been achieved. Why should there be more progress in the future?

Nuclear energy is still perceived as an high-end and modern technology by many nations. Thus it is viewed as a natural way to modernize. Not all countries will have the economic resources to pursue this path, but those who can afford it might choose the nuclear option. As long as Western countries interested in profitably exporting nuclear facilities present nuclear power as a modern and environmentally clean and cheap source of energy, they will encourage new countries to engage in the use of nuclear technology. By doing so, they will inevitably worsen proliferation risks.[31]

Finally, a reminder: The NPT and the nonproliferation system created between the late sixties and the beginning of the twenty-first century were based on an underlying deal already mentioned; it is possible to strengthen nonproliferation and make nonproliferation arrangements more effective. However, to do so requires political will. Whether this will exists depends on the visible progress made on nuclear arms control and disarmament. The current lack of political will to achieve progress in the disarmament field can backfire on the political will to support a strengthened nonproliferation regime. In such a case, the nonproliferation regime is likely to be weakened instead of being strengthened.

[30] Frank et al., Nuclear Energy and Nuclear Weapons Proliferation, 1979.

[31] It might be worth considering portraying nuclear energy as an outmoded technology. Today, in a growing number of countries, most highly trained and skilled technicians, engineers, and scientists are working on technologies to increase energy efficiency or renewables than on nuclear technologies.

5 Additional information

The issues covered by this paper are dealt with in a huge number of official documents and research publications. The literature mentioned below is either "standard publications" or recent and easy-to-access material offering additional information in the case of need, interest, or demand. The materials are organized in three categories: Official documents, studies and analysis, and useful internet websites.

Some important official documents:

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Spector, Leonard and Jacqueline R. Smith. Nuclear Ambitions. Boulder/San Francisco/Oxford: 1990.

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Useful websites:

International Atomic Energy Agency – http://www.iaea.org

Nuclear Suppliers Group – http://www.nuclearsuppliersgroup.org/

United Nations – http://www.un.org

Arms Control Association – http://www.armscontrol.org

Bulletin Of Atomic Scientists – http://www.thebulletin.org

Carnegie Endowment for International Peace – http://www.ceip.org

Federation of American Scientists – http://www.fas.org

Globalsecurity.org (Country Profiles) – http://www.globalsecurity.org/wmd/world/index.html

Institute for Science and International Security – http://www.isis-online.org

Managing the Atom Project, Belfer Center, Harvard University – http://bcsia.ksg.harvard.edu/research.cfm?program=STPP&project=MTA&pb_id=240&gma=27&gmi=47

Monterey Institute for International Security – http://cns.miis.edu/

Nuclear Threat Initiative: – http://www.nti.org

Nuclear Threat Initiative (Country Profiles) – http://www.nti.org/e_research/profiles/index.html

Russian American Nuclear Advisory Committee – http://www.ransac.org

Peace Research Institute Frankfurt – http://www.hsfk.de

Women's International League for Peace and Freedom – http://www.reachingcriticalwill.org

Verification Technology Information Centre – http://www.vertic.org.uk

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