



Chapter seven

Assessing the proliferation risks of civilian nuclear programmes

Nuclear power plants alone are not a proliferation risk. Without enrichment or reprocessing capabilities, power-reactor fuel, whether fresh or spent, cannot be used for the production of nuclear weapons. There are various ways, however, in which reactor projects and related nuclear fuel-cycle facilities could be used to further a nuclear-weapons development programme. This chapter describes these various possible proliferation pathways. It should be stressed that no successful nuclear-weapons programme has ever relied on commercial reactors. Most of the states that have pursued weapons programmes went on to construct nuclear power plants, but only after their dedicated military programmes were successful, nearing success or had been abandoned. The scenarios for proliferation activities related to nuclear power plants described here are, therefore, only hypothetical, but they cannot be ruled out, especially in light of the increasing availability of nuclear-weapons-related technologies spread by black-market networks.¹

As outlined in the introduction to this dossier, IAEA standard safeguards are designed to detect in a timely manner the diversion of nuclear material from declared nuclear facilities. Diverting material from declared and safeguarded fuel-cycle facilities is difficult; it is likely that a would-be nuclear-weapons state would construct clandestine facilities as part of a parallel secret programme. The effectiveness of IAEA safeguards, even with the strengthening provisions of the Additional Protocol, varies according to the type of facility in question. Nuclear power plants themselves are relatively straightforward to safeguard. Detecting diversion at facilities which handle large quantities of liquids, gases or powders (known as bulk-handling facilities), such as full-scale enrichment or reprocessing plants, is more of a challenge. Detecting the exist-

ence of small clandestine gas-centrifuge enrichment plants is the greatest challenge. Unlike reactors or reprocessing plants, such facilities produce very few environmental emissions or other transmissible signatures, and so can be extremely difficult to detect. Enrichment plants can also be housed in small and nondescript facilities, or buried underground, and thus can be hard to discern from overhead imagery. A state that complements a nuclear-reactor programme with such sensitive fuel-cycle technologies (which could be replicated in secret) thus presents a possible proliferation concern.

In the event that a violation is detected, any enforcement actions are at the discretion of the IAEA board of governors and the United Nations Security Council. The efficacy of the system for ensuring compliance with safeguards agreements is therefore dependent on the effectiveness of IAEA safeguards, the mechanisms for agreeing on enforcement actions and the enforcement actions themselves.

Sources of plutonium

In all nuclear reactors, the irradiation of uranium fuel produces plutonium, among other products. In military-dedicated reactors (including research reactors that are actually operated for weapons purposes), plutonium production is the intent. In civilian power reactors, plutonium is a by-product of electricity generation. For plutonium to be used in a nuclear weapon, it has to be separated out from the other materials and fission products that make up most of the spent fuel. The spent fuel contains highly radioactive fission products. Separating plutonium from spent fuel without posing a severe hazard to workers requires a heavily shielded dedicated facility and a series of remotely operated chemical separation steps.

Power reactors

The plutonium produced as a by-product of nuclear-power generation can be used to make a nuclear device, though it is not optimal.² The problems associated with the use of power-reactor fuel come about as a result of the length of time for which fuel is irradiated in this type of reactor. If reactor operators remove the spent fuel after a low 'burn-up' (a few weeks of irradiation), the plutonium will have a high concentration of Pu-239, the plutonium isotope best suited for use in a nuclear weapon. In practice, however, reactor operators normally irradiate fuel for two to six years, which results in 'reactor-grade plutonium' that has a larger quantity of other, less desirable, plutonium isotopes. The isotopes Pu-238 and Pu-240 are particularly problematic because they have a high spontaneous fission rate that could cause premature initiation of the chain reaction resulting in a dramatically reduced explosive yield. The heat emitted by the alpha decay of the Pu-238 isotope and the intense gamma radiation emitted by Pu-241 and its decay products also complicate the use of reactor-grade plutonium in a nuclear weapon. But although a weapon using reactor-grade fissile material would tend to have an unreliable yield, even a 'fizzle' (a partial explosion) would still create a very large blast. North Korea's 9 October 2006 test is often described as a fizzle (though the cause of failure remains a matter for speculation), as it had a yield of less than 1 kilotonne of TNT.

Whether or not a would-be nuclear power could build a successful nuclear weapon using reactor-grade plutonium is a difficult judgment to make without access to classified information.³ The use of reactor-grade plutonium would be likely to reduce the predictability of the weapons' yield, as new proliferators are unlikely to have access to advanced weapons designs that could overcome the pre-ignition problem.⁴ But whether this would deter a proliferator from trying – given that a fizzle might well be as powerful as a thousand large Second World War bombs – is unclear.

Power reactors fuelled with natural (or slightly enriched) uranium and moderated by heavy water or graphite produce spent fuel that is somewhat more suitable for nuclear weapons than is the spent fuel from light-water reactors (LWRs). Today, such reactors are rarely constructed for civilian power generation, though there is some interest in them

IAEA inspections

The activities that IAEA inspectors perform during inspections include:

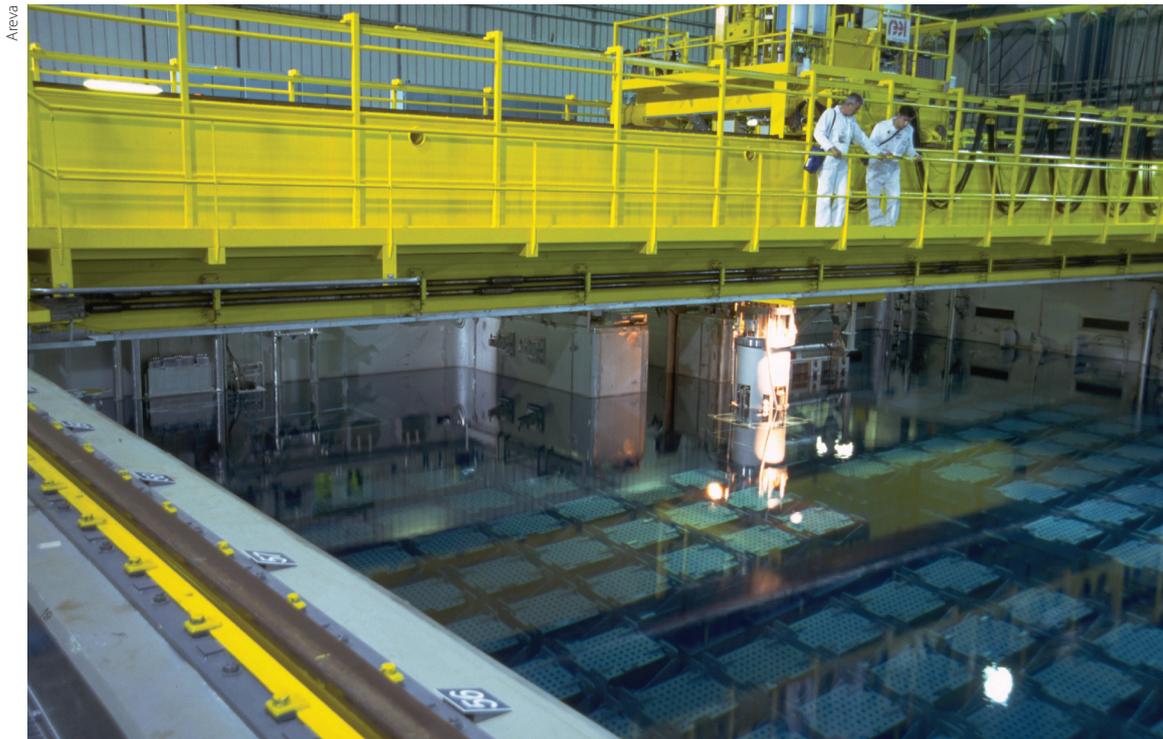
- examining facility records and comparing them with reports submitted by the state;
- verifying declared inventories and flows of nuclear material (e.g., through item counting, non-destructive assay measurements, material sampling for destructive analysis);
- verifying, under item-specific agreements, certain non-nuclear material and equipment;
- applying containment and surveillance measures;
- confirming the absence of undeclared activities (e.g. unreported nuclear production at reactors, or the undeclared use of reprocessing and enrichment plants or hot cells), such as through taking environmental samples; and
- confirming the absence of borrowed nuclear material from another facility in the state that could be used to conceal diversion.

Source: The Safeguards System of the International Atomic Energy Agency, http://www.iaea.org/OurWork/SV/Safeguards/safeg_system.pdf, p. 12.

as research reactors; examples are the facility Iran is building at Arak and the Es Salam reactor in Algeria.

LWRs have an additional proliferation-resistant feature in that their fuel cannot be loaded or removed without the entire power plant shutting down, which in principle should be readily observable by international inspectors or remote monitoring equipment. By contrast, reactors moderated by graphite or heavy water continue to operate during refuelling, thereby complicating safeguards against diversion.

Because of the way in which nuclear reactors are refuelled, fuel assemblies discharged from a reactor's core during the first refuelling are irradiated for a considerably shorter period of time than those normally discharged in subsequent refuellings. They therefore contain a higher proportion of Pu-239. In addition, fuel assemblies near the periphery of the core are irradiated less than those near the centre. Therefore, assemblies near the periphery of the core, particularly those of the first two discharges, are the most desirable to divert. The fuel assembly of a large power reactor can contain four to six kilogrammes



Spent-fuel cooling pond

of plutonium – approximately the amount of plutonium in a nuclear weapon.

If the location within a reactor's spent-fuel pond of those assemblies with high-grade plutonium content was clearly marked, it might be possible for preparations to be made for their clandestine removal and reprocessing. The diversion of assemblies from a nuclear power plant's spent-fuel pool has never been accomplished, so far as is known, and would be very difficult, if not impossible, to achieve, given that IAEA safeguards cameras permanently survey spent-fuel ponds and transmit the images to IAEA headquarters in Vienna. Nevertheless, future would-be proliferators might be tempted to attempt such a diversion if other means of obtaining fissile material proved more difficult. This hypothetical scenario might involve the blocking of the IAEA cameras and the replacement of diverted assemblies with dummy replicas yielding similar radiation signatures. Although its successful accomplishment would require the clockwork operation of many steps and good luck at every stage, the possibility of such a diversion cannot be dismissed.

Research reactors

Research reactors produce much smaller amounts of fissile material than power reactors, but they

have several other features that make them potentially amenable to non-peaceful use. Indeed, 'research reactor' is a misnomer for the plants of this type that have been used for dedicated nuclear-weapons purposes in several countries. Research reactors are relatively affordable, and require no more than a few dozen staff in total to operate them. Because their fuel burn-up is usually low, research reactors often produce weapons-grade or near-weapons-grade plutonium. The quantity of plutonium produced annually in a research reactor such as Egypt's ETRR-2 could be equal to around one critical mass (the smallest amount needed for a sustained chain reaction), were that plutonium to be clandestinely extracted. The spent fuel accumulated by the ETRR-2 over its ten years of operation to date is likely to be equivalent to eight to ten weapons' worth of plutonium, if reprocessed. The longer spent fuel accumulates in the storage pool, the more the self-protecting radiation barrier of that fuel is reduced. The radioactivity of spent fuel declines with a half life of around 30 years (based on the radioactive half lives of the cesium-137 and strontium-90 isotopes), making the fuel less dangerous to handle and process as it declines, with potential proliferation implications.⁵

Proliferation from the accumulated spent-fuel inventory could follow a number of hypothetical routes. In the case of a nuclear break-out, that is, a state's withdrawal from the NPT to openly pursue a nuclear-weapons capability (see below), all the accumulated spent fuel could be removed from the storage pond for plutonium separation, if the state already had a reprocessing plant or hot cells. Alternatively, spent fuel assemblies could be clandestinely diverted from the storage pond and replaced with dummy assemblies. Another hypothetical route to proliferation using a research reactor would be through the clandestine positioning of natural uranium assemblies around the reactor's core to form an effective 'blanket' in which plutonium could be bred, or the replacement of some fuel rods with natural uranium rods. This proliferation pathway is highly sensitive to reactor design, and is easier in the case of research reactors with a high neutrons flux, such as those in Algeria, Egypt and Libya, and Iraq's Osirak reactor, destroyed by Israel in 1981. Covert positioning of additional fuel assemblies around the periphery of the core and their removal would have to be done while safeguards inspectors were absent, and would have to be conducted in a way that would appear innocuous to the IAEA camera pointed at the reactor's pool.

Reprocessing facilities

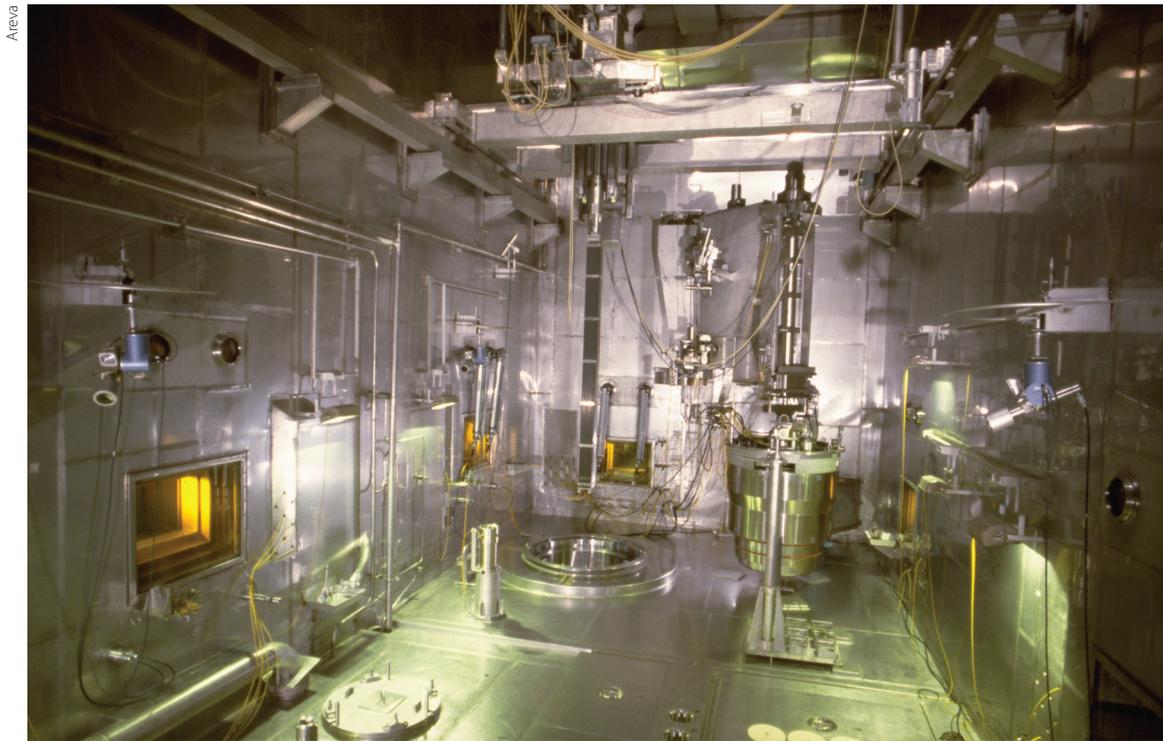
In order to separate plutonium for a secret nuclear-weapons programme, an aspiring nuclear-weapons state would have to design, construct and operate a clandestine reprocessing facility. Such a facility would be a relatively large, expensive operation that would be difficult to disguise. Although it is theoretically possible to construct a small reprocessing plant with around 20 tonnes of heavy metal (MTHM) annual capacity (a fifth of the size of North Korea's 100MTHM-per-year plant at Yongbyon), this has never been carried out in practice, so far as is known. A more realistic scenario for a clandestine plant would be an intermediate size of the order of 30–50MTHM per year, similar to that of the first Indian reprocessing plant at Trombay. A plant of this size, while relatively large, could still be camouflaged as an industrial building, or be constructed inside a large tunnel. Nevertheless, the likelihood of being able to construct and operate it secretly for a sustained period of time is low. In addition,

the equipment required to chop, dissolve and separate out the constituents of a spent fuel assembly is difficult to procure, hide or remove, and would constitute strong evidence of a clandestine weapons effort if discovered.

A hot-cell complex built as part of a declared nuclear infrastructure could possibly be used for some clandestine reprocessing, but might not be sufficiently shielded to handle the radioactivity emanating from a power reactor's spent fuel assembly, unless the assembly was only lightly irradiated, or it had been stored in the pool for a long period of time. For research and training in radioactive materials, some states, including Algeria, Egypt, Iran and Israel, have constructed hot-cell complexes where irradiated fuel can be separated in small quantities. All these facilities are operated under IAEA safeguards. Future use of hot cell facilities for small-scale batch reprocessing for weapons purposes cannot be ruled out. Both Egypt and Iran have admitted to the small-scale reprocessing of irradiated uranium targets to separate out minuscule amounts of plutonium in the past, activity that was only reported to the IAEA many years later.

A declared reprocessing centre could aid a clandestine weapons programme in several ways. Firstly, its hot cells could be used to study, simulate and support the operation of a larger clandestine reprocessing centre located elsewhere. The proposed process for the clandestine separation plant could be tried out on a smaller scale in the hot-cells complex between IAEA inspection visits, while support could be provided through the designing or building of protective gloveboxes for finished-product handling.

Secondly, the operators of a reprocessing plant could attempt to falsify the performance records of the plant and operate it at capacity factors higher than those reported to the IAEA. The extra separated plutonium thus produced could be diverted to the weapons programme. Alternatively, plutonium product might be diverted from the plant while being reported to the IAEA as material unaccounted for (MUF). MUF is the standard accounting term for the difference between the amount of material that ought to be present and the amount that actually is present. Some MUF is inevitable, due both to the uncertainties inherent in measurement systems and to accumulation in plant flow pipes. But it could also



Interior of a hot cell

result from a diversion of nuclear material. Even a small reprocessing plant with a capacity of roughly 50MTHM per year could, assuming the reprocessed spent fuel is around 1% plutonium, separate up to 500kg of plutonium a year. The 1–2% of missing output typically designated as MUF would thus be equivalent to five to 10kg of plutonium per year – enough for one or two warheads. If a plant's real MUF is 1%, the plant operators might therefore declare it to be 2%, and divert the difference.

Sources of HEU

Fresh fuel for power reactors is unsuitable for use in a weapon unless it is subsequently enriched to more than 20% U-235. (Although HEU is not considered to be weapons-grade until it is 93–94% U-235, weapons like the one dropped on Hiroshima can be made with HEU enriched to as little as 80%.) The fuel used in heavy-water reactors is usually natural uranium, with 0.7% U-235. LWRs use low-enriched uranium (LEU) fuel, in the form of uranium oxide pellets of 3.5% to 5% enriched uranium, enclosed within a sealed fuel assembly. Enriching this for weapons use requires a dedicated enrichment plant.

IAEA safeguards are designed to detect the diversion of fresh fuel from nuclear reactors. It might

be possible for a determined proliferator to divert without timely detection, especially where permanent on-site inspectors or real-time remote camera surveillance are absent, as they often are. Given the likelihood of eventual detection, however, such diversion would probably take place in conjunction with a decision to break out of the NPT. In the case of a break-out, the fresh fuel could be seized, converted to a chemical form suitable for enrichment and fed into a clandestine or previously declared cascade that had been removed from the inspections regime. If the material inputted into an enrichment cascade is LEU, rather than natural uranium, the amount of enrichment work required (measured in separative work units) per unit of HEU product is reduced by a factor of more than three. The fresh fuel stored at research reactors, being typically more highly enriched than the fuel in power reactors, presents a particular proliferation risk in the case of break-out. This is especially the case if the fuel is HEU, as it is in approximately 125 research reactors in nearly 40 countries.⁶

Enrichment plants

With all the countries in the Middle East except for Israel party to the NPT, it is likely that any future



Fuel pellets

enrichment plants in the region will operate under IAEA safeguards. It would be very difficult to use such plants in a weapons-proliferation programme without being detected or breaking out of the NPT. A safeguarded enrichment plant could, however, support a parallel weapons programme in more than one way.

Firstly, a declared plant could be operated at higher capacity than reported to the IAEA, in a procedure similar to the reprocessing scenario described above. Data on input feed to the plant and product withdrawal could be falsified by the operators to hide greater plant throughput, and undeclared enriched-uranium product could be siphoned off to the clandestine facility for further enrichment.

The basic problem with this scenario, which is known as 'excess production', concerns the extra fresh uranium feed. Assuming the IAEA has a record of the uranium feed obtained by the country in question, and can calculate how much feed would be required to produce the reported LEU product, then it should be able to determine if clandestine overfeeding of the enrichment cascade has occurred. A determined proliferator proceeding with this diversion scenario would therefore need to acquire an unreported uranium supply, as well as a mill and a conversion plant that could feed uranium hexafluoride (UF_6), the main uranium compound suitable for enrichment, to the declared cascade in the secret enrichment operation. This clandestine uranium supply could come from a domestic mine, should one exist, or it could be covertly purchased

abroad and imported without declaring it to the IAEA. A country operating domestic uranium mines and an enrichment plant, even a declared one, enjoys a heightened potential for enriched-uranium diversion. In a diversion scenario, mine operators could falsify the mine's output records to hide a higher uranium production rate than reported to the IAEA, which does not verify mine production under

standard safeguards and only verifies to within an order of magnitude under the Additional Protocol.

Depending on the exact way in which IAEA safeguards were implemented in the country, it might even be possible to modify the piping configuration of a portion of the declared plant so as to effectively create a new cascade with which to re-enrich the extra LEU created by excess production to HEU level. The piping configuration could then be modified back to its original form prior to the next IAEA inspector's visit. Alternatively, the LEU could be transported for re-enrichment to a small clandestine enrichment plant located elsewhere.

Secondly, a declared enrichment plant would be useful to a parallel clandestine programme in terms of providing operating experience and personnel training, as well as information about plant design, equipment characteristics and operating conditions. The secret installation need not be of the same type, however. It might use a second technology to further hamper detection. Although the gas centrifuge process is the most commercially viable and, thanks to A.Q. Khan, the most widespread technology, proliferators could also turn to obsolete, yet sufficient, technologies such as electromagnetic isotope separation and chemical exchange. Scientists trained in modern and open commercial programmes could be transferred to a clandestine facility that used simpler technology that was easier to construct and did not require significant amounts of traceable, controlled commodities such as maraging steel or ring magnets.

Conversion or fabrication plants

Uranium conversion plants, which convert yellowcake to UF₆ and other compounds suitable for enrichment, are not normally safeguarded from the beginning of the conversion process. Certain material flows could therefore be diverted to a clandestine enrichment plant or used for excess production in a declared enrichment plant. Fabrication plants, which handle only LEU-grade material, are considered the least diversion-sensitive part of the front end of the nuclear fuel cycle. The IAEA's input-output material accounting as it is applied to a fabrication plant guarantees that no diversion occurs during routine operations while under the safeguards inspections regime. The use of a fabrication plant in a nuclear-weapons programme, or the diversion of material from it, could, therefore, occur only in a nuclear break-out situation.

Sources of other materials and expertise

Civilian nuclear programmes can facilitate illicit procurement and provide technology and expertise to support a clandestine programme. The large volume of foreign procurement necessary for nuclear-power-plant construction in the Middle East means that here, as in most other areas of the world, it is possible that the procurement of dual-use items or materials requested by a parallel weapons programme could be accomplished without suspicions being raised. This is one of the reasons why Western states opposed the sale of material and equipment for Iran's Bushehr reactor.

Such covert procurement may be more likely in the case of plants provided by new suppliers outside the small circle of international corporations that now account for most nuclear-power-plant construction. A worldwide expansion in demand for nuclear power may entice new suppliers from countries such as China, where export controls have been problematic. A supplier eager to secure a multi-billion-dollar contract might turn a blind eye to covert procurement. Most likely, clandestine transfers would not be handled by the supplier itself, but rather by an affiliated trading company or a trusted network of middlemen. Several different middlemen may be used to transfer different technical components of a specific equipment system and to handle money transfers, as happened in the Khan network's dealings with Libya. Trans-shipped

equipment could be mislabelled as a different type of product, and end-use certificates and final destinations falsified. Multiple trans-shipments and the use of free-trade zones can help disguise ownership, documentation and destination.

Any large-scale technology-related project will employ and train many engineers and scientists, some of whom will develop and exhibit management capabilities. Some of the capable and ambitious managers identified during the construction phase of a large nuclear power plant might be reassigned to a parallel clandestine national proliferation programme. The importance of managerial expertise to a national nuclear-weapons programme cannot be underestimated, as demonstrated by the success of South Africa's programme, led by a team of able managers, and the achievements of lead programme managers such as Robert Oppenheimer in the US, Igor Kurchatov in the Soviet Union and Homi Bhabha in India. Conversely, the problems encountered by Iraq's programme can partly be ascribed to a lack of effective management.

As discussed in regard to enrichment plants, declared fuel-cycle facilities could also provide direct training value to a clandestine weapons programme. A legitimate enrichment or reprocessing plant would train a large number of plant operators in the exacting discipline of handling bulk quantities of radioactive substances. If their career paths were not subsequently monitored, these trained personnel could apply their newly acquired skills and experience to a clandestine programme.

NPT break-out scenarios

A state with a nuclear reactor that decided to break out of the NPT could try to obtain weapons material either by converting partially enriched fresh fuel or, more likely, by separating plutonium from spent fuel. A break-out attempt involving an operating nuclear power plant would be likely to have severe international consequences, including the cutting off of fresh fuel imports for power reactors, economic sanctions and, perhaps, a military attack. The state concerned would have to weigh the value of obtaining fissile material against these consequences.

From a proliferator's point of view, for break-out to be judged worthwhile, and preferable to operating a parallel clandestine programme while

still party to the NPT, timing would be crucial. Article X of the NPT requires that parties give 90 days' notice of withdrawal from the treaty. In order to achieve near-term results, therefore, break-out would probably be timed to take place just after a new fuel reload had arrived, so that the state would have enriched uranium available imminently, or lightly irradiated plutonium, closer to weapons-grade level, available for recovery a few weeks later. A break-out would have to be planned well in advance to allow the proliferator time to construct either a conversion facility and an enrichment plant or a reprocessing plant.

The amounts of uranium involved in a break-out scenario could be significant. The fresh-fuel annual reload for a 1,000MW reactor weighs about 23 tonnes. At a U-235 concentration of 4.5% in LEU, the total amount of U-235 in that load exceeds one tonne. If converted and re-enriched to weapons grade, the entire reload could provide enough fissile material for many warheads. A break-out scenario could involve the fresh fuel assemblies being removed from the reactor and transferred to a facility where the oxide-form LEU pellets could be removed from their assembly configuration, crushed and then fluorinated to yield UF_6 , in preparation for further enrichment.

Multi-country joint break-out scenarios

The above discussion concerns a proliferating country which has an operating reactor and a parallel clandestine fuel-cycle facility prior to break-out. But a division of labour among states is also hypothetically possible. One country could concentrate on constructing and operating a reactor in an open manner within the NPT safeguards regime, while another like-minded country could at the same time develop covert fuel-cycle facilities (a conversion and enrichment capability, or a reprocessing plant), in the expectation that it would not be detected. It would be essential that the country choosing to construct the clandestine fuel-cycle facility had developed some prior nuclear infrastructure and a cadre of trained personnel that could be assigned to the secret plant.

Once both states were ready – one with its operating reactor, the other with a working clandestine fuel-cycle facility – then, hypothetically, they could break out of the NPT regime simultaneously,

renounce their safeguards obligations and start an open joint proliferation programme, removing material from the operating reactor in one country for processing in the hitherto clandestine fuel-cycle facility in the other. The fissile material obtained from such a joint programme could be shared between the participants. Should such a scenario prove successful, other like-minded regional states with budding nuclear programmes might then join in. There have been several examples of countries abetting the nuclear proliferation of allies in the past, for instance China's assistance to Pakistan's weapons programme and Pakistan's purported assistance to North Korea and Iran.⁷ Such precedents are reason not to rule out future coordinated NPT break-out attempts.

A possible subgroup of the putative joint multi-state break-out scenario is 'assisted break-out', in which one state openly breaks out of the NPT regime and rescinds all its safeguards obligations, while a like-minded state remaining in the NPT continues to provide it with clandestine nuclear-proliferation support.

Conclusion

It is not easy to divert fissile material from declared facilities operated under the IAEA safeguards regime. A civilian nuclear-energy programme could nevertheless support a parallel clandestine nuclear-weapons development project directly and (mostly) indirectly. Diversion might be possible through the use of falsified operations records to enable operation at higher capacity factors than reported and the removal of incremental amounts of product from declared facilities to a parallel clandestine programme. Such operations would require a source of undeclared natural uranium as the start-up feed material.

Yet nuclear power plants cannot be considered proliferation nodes in the absence of supporting fuel-cycle facilities. In fact, a country's interest in fuel-cycle facilities is a far better indicator of possible interest in developing covert or overt nuclear-weapons production capabilities than is the operation of commercial reactors alone. Clandestine enrichment of an illicit uranium supply completely divorced from reactor operation is perhaps the easiest proliferation pathway, if a secret source of uranium can be obtained. A country operating both

uranium mines and enrichment facilities might thus be best positioned to proliferate, should it choose to do so.

The option most likely to yield fissile material for weapons is the dedicated, covert production facilities route. The existence of a civilian nuclear-energy programme could mask the development of some components of such a clandestine operation by enabling them to be disguised as declared infrastructure facilities. The civilian programme could provide further support to the clandestine one in terms of personnel training, process design, procurement and operational simulation. Nevertheless, a concealed weapons programme could proceed with its own dedicated facilities without the support of civilian energy-generation facilities.

The NPT/IAEA safeguards system, buttressed by the Additional Protocol, is currently the best bulwark against proliferation. By corollary, a state that exer-

cised its right to withdraw from the NPT would pose a serious challenge to the regime. Much of the civilian nuclear-energy infrastructure constructed prior to withdrawal from the treaty could be useful to a parallel secret programme. Once break-out were announced, any clandestine facilities could openly mesh with existing nuclear-energy facilities. In such a case, any available fresh nuclear fuel or low-burn-up spent fuel assemblies from a nuclear-energy programme could be used to contribute to the open pursuit of a weapons programme. An assisted or joint break-out involving at least two like-minded countries synergistically using their combined facilities for a collaborative weapons programme is a further possible, though more remote, scenario. The most pressing proliferation threat, however, is that posed by a state which has civilian fuel-cycle facilities in conjunction with a parallel secret weapons programme.

Notes

- 1 This chapter draws on a presentation by Chaim Braun on 'Possible Weapons Proliferation from Proposed "Nuclear Power" Programs in the Middle East' at the James Martin Center for Nonproliferation Studies, Monterey Institute of International Studies, 2 November 2007.
- 2 In 1962, the United States successfully tested a nuclear device using reactor-grade plutonium. It had a yield of less than 20 kilotonnes.
- 3 There is a lively debate among experts. See for example J. Carson Mark, 'Explosive Properties of Reactor-Grade Plutonium', *Science and Global Security*, vol. 4, 1993, pp. 111–128; Bruno Pellaud, 'Proliferation Aspects of Plutonium Recycling', *Journal of Nuclear Materials Management*, vol. 31, no. 1, Fall 2002, pp. 30–38; and Australian Safeguards and Non-Proliferation Office, 'Reactor-Grade Plutonium: Use In Nuclear Weapon Tests', ASNO Information Sheet, December 2006, http://www.asno.dfat.gov.au/infosheets/rgp_deco6.pdf.
- 4 For a useful discussion of the advanced weapons design argument and other factors relating to the proliferation danger of power reactors, see Victor Gilinsky, Marvin Miller and Harmon Hubbard, 'A Fresh Examination of the Proliferation Dangers of Light Water Reactors', Nonproliferation Policy Education Center, 22 October 2004, <http://www.npec-web.org/Essays/20041022-GilinskyEtAl-LWR.pdf>.
- 5 This is worth noting in particular in regard to the Es Salam reactor in Algeria, where some of the spent fuel has been in the storage pool for over 16 years.
- 6 According to Matthew Bunn, as of the end of 2006, 'roughly 140' research reactors and critical assemblies used HEU. Matthew Bunn, 'Securing the Bomb 2007', Project on Managing the Atom, Harvard University and the Nuclear Threat Initiative, 26 September 2007. In 2007, ten HEU reactors were converted or shut down under the US Global Threat Reduction Initiative. See 'Detailed Information on the National Nuclear Security Administration: Global Threat Reduction Initiative Program Assessment', <http://www.whitehouse.gov/omb/expectmore/detail/10003239.2006.html>.
- 7 In fact, almost every proliferating country has benefited from foreign assistance, either official or private, to some degree. See International Institute for Strategic Studies, *Nuclear Black Markets: A.Q. Khan, Pakistan and the Rise of Proliferation Networks: A net assessment* (London: IISS, 2007), p. 8.

