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The Nuclear Fuel Cycle and Horizontal Proliferation in the Asia-Pacific Region

John Carlson

Introduction

Horizontal proliferation refers to the acquisition of nuclear weapons by states additional to those already possessing such weapons. Nuclear weapons cannot be produced without fissile materials, namely, highly enriched uranium (HEU) or separated plutonium. Producing these materials requires respectively uranium enrichment and reprocessing capabilities. The difficulty of developing these capabilities remains a major obstacle to nuclear proliferation.

Historically, states pursuing nuclear weapons have usually sought to develop enrichment or reprocessing facilities in secret. An alternative approach, however, is to establish these openly, as part of the civilian nuclear fuel cycle. Enrichment and reprocessing are described as sensitive nuclear technologies because they are potentially dual purpose: they were developed originally for military purposes and a state that acquires these capabilities for peaceful use could decide to turn them to producing nuclear weapons. A state with such capabilities is described as having nuclear latency. This is not to say that a state pursuing enrichment or reprocessing intends to produce nuclear weapons, but such a state presents the international community with a dilemma: how to ensure the spread of fuel cycle capabilities does not increase the risk of nuclear weapons proliferation. This paper discusses this problem with particular reference to the Asia-Pacific context.

Asia-Pacific Region

This paper adopts the delineation of the Asia-Pacific region used by APLN (the Asia-Pacific Leadership Network for Nuclear Non-Proliferation and Disarmament): the area comprising North Asia, South Asia, Southeast Asia, and the Southwest Pacific. This is an extensive and diverse geographic area. States in the region include:

- Two of the five nuclear-weapon states recognized by the Non-Proliferation Treaty (NPT)—China and Russia;
- Three of the four nuclear-armed states not parties to the NPT—India, Pakistan, and the DPRK.

The United States, while outside the region, is deeply engaged in the region, including through defence alliances with several states.

Reflecting the competing interests of these various states, the Asia-Pacific is notable for containing a number of areas of tension and conflict, actual and potential, between nuclear-armed states. In this regard critical interactions include those between India and Pakistan, India and China, the DPRK and the United States and US allies; and China and the United States. As will be discussed, strategic threats, instabilities, and uncertainties contribute to proliferation pressures—as demonstrated by the actions of India, Pakistan, and the DPRK in developing nuclear weapons and by public debate about doing so in Japan, the ROK, and elsewhere. The region thus figures prominently in global proliferation concerns.

What is Meant by Horizontal Proliferation?

In the nuclear context, *horizontal proliferation* refers to an increase in the number of states with nuclear weapons. In the mid-1960s when the NPT was negotiated it was feared that the number of states with nuclear weapons would increase substantially, from the five that existed at that time to possibly twenty-five to thirty by 1990. Horizontal proliferation is distinct from *vertical proliferation*, which refers to an increase in the number of nuclear weapons held by nuclear-armed states, exemplified by the arms race between the United States and the Soviet Union in the 1950s and 60s. Unless a contrary intention is indicated, *proliferation* is generally taken to mean horizontal proliferation.

Horizontal proliferation can be thought of as having three phases. The first phase, the pre-NPT period, lasted from 1945 to the conclusion of the NPT in 1968. In this period the United States' monopoly over nuclear weapons was broken first by the Soviet Union. Subsequently, the United Kingdom, France, and China also acquired nuclear weapons. When the NPT was negotiated these five became the recognized *nuclear-weapon states*. Over this period many other states were actively considering acquiring nuclear weapons, a situation which prompted the negotiation of the NPT.

The second phase lasted from the conclusion of the NPT until the treaty's indefinite extension in 1995. Over this period the NPT's membership gradually expanded and by 1995 was close to universal. During this period, however, nuclear weapons were developed by India, Israel, and Pakistan. These states never joined the NPT and remain outside it. Also, during this period South Africa developed nuclear weapons, while outside the NPT. Subsequently South Africa dismantled its nuclear weapons—so far, the only nuclear-armed state to do so—and joined the NPT in 1991.

Towards the end of this period, as the NPT drew closer to universality, the term *proliferation* acquired its contemporary meaning: the pursuit of nuclear weapons in violation of the NPT. The most familiar example is Iraq, which established a secret nuclear program. Because this program had no obvious links to its declared program, it eluded detection for many years. The International Atomic Energy Agency (IAEA) found Iraq was in non-compliance with its safeguards agreement in 1991. As a consequence, Iraq's actions also constituted a violation of the NPT. In addition to Iraq, the IAEA has found five other states in non-compliance with their NPT safeguards agreements, two during this period: Romania (1992) and the DPRK (1993). The DPRK is notable for being the only case of NPT violation where the state concerned has succeeded in acquiring nuclear weapons.

The current phase dates from 1995. The NPT is now almost universal, with only India, Israel, and Pakistan remaining outside, together with the DPRK, which withdrew from the treaty in 2003.[1] During this period the IAEA found three further states in safeguards non-compliance: Libya

[1] The validity of the DPRK's withdrawal from the NPT has not been definitively determined. The IAEA sought guidance from NPT parties on the legal status of the withdrawal but such guidance has not been forthcoming. See IAEA Fact Sheet on DPRK Nuclear Safeguards, https://www.iaea.org/newscenter/focus/dprk/fact-sheet-on-dprk-nuclear-safeguards.

(2004), Iran (2006), and Syria (2011). All six safeguards non-compliance cases included development or acquisition of enrichment or reprocessing technologies in secret, in violation of safeguards agreements and the NPT.

In contrast to these non-compliance cases, preparation for nuclear weapons does not necessarily have to proceed in secret. In the 1970s there were a number of cases where the transfer of enrichment or reprocessing capabilities was sought openly, for ostensibly peaceful purposes. These included supply by France of reprocessing plants to the ROK, Pakistan, and Taiwan, and supply by Germany of a reprocessing plant to Taiwan and enrichment and reprocessing plants to Brazil. These transfers were discontinued due to international concerns about their potential proliferation.

India's 1974 nuclear test, using plutonium in violation of peaceful use assurances given to Canada and the United States, alerted governments to the dangers of misuse of supplied technology, and these various proposals for supply of sensitive facilities added to these concerns. The outcome was the establishment of the Nuclear Suppliers Group (NSG) in 1974. The objective of the NSG was to prevent nuclear proliferation by controlling the export of materials, equipment, and technology that can be used to produce nuclear weapons.

Finally, it is noted that the term *horizontal proliferation* could also apply to the acquisition of nuclear weapons by non-state actors. This involves a different range of issues to proliferation by states and is beyond the scope of this paper.

The Non-proliferation Regime and Proliferation-sensitive Technology

The Non-Proliferation Treaty, concluded in 1968, is the centrepiece of the non-proliferation regime. The NPT's key provisions are summarized as follows:

- The states that had conducted a nuclear test prior to 1967 were categorized as *nuclear-weapon states*. There are five such states: the United States, Russia, the United Kingdom, France, and China. The nuclear-weapon states commit not to assist others in acquiring nuclear weapons (Article I).

- All other parties are categorized as *non-nuclear-weapon states*. These states commit not to seek nuclear weapons and to accept IAEA safeguards on all their nuclear material to verify that nuclear energy is not diverted to producing nuclear weapons (Article III).
- The NPT is expressed not to affect the right of the parties to research, production, and use of nuclear energy for peaceful purposes provided this is in conformity with the treaty. The parties undertake to cooperate in the peaceful uses of nuclear energy (Article IV).
- All parties undertake to pursue nuclear and general disarmament (Article VI).

The NPT is complemented and reinforced by a number of other treaties, arrangements, and mechanisms, including:

- IAEA safeguards: These are of crucial importance as the verification mechanism for the NPT's non-proliferation provisions. The key objectives of IAEA safeguards are the *timely detection* of diversion of nuclear material from peaceful nuclear activities to nuclear weapons and *deterrence* of such diversion by the risk of early detection.
- Bilateral agreements, particularly nuclear cooperation agreements applying peaceful use and safeguards conditions. Notable in this regard are agreements that require the supplier party's prior consent to enrichment and reprocessing, or expressly exclude these activities.
- Regional treaties, such as the Euratom Treaty and the various nuclear weapon-free zone treaties.[2]
- National export controls on nuclear and nuclear-related materials, items, equipment, and technologies, especially as coordinated through the NSG.
- Convention on the Physical Protection of Nuclear Material.
- Comprehensive Nuclear-Test-Ban Treaty.

As noted earlier, the impetus for negotiating the NPT was the concern that the number of states having nuclear weapons would increase substantially unless something was done. While the

[2] The Asia-Pacific region has three nuclear weapon-free zones: the South Pacific Nuclear-Free Zone, the Southeast Asia Nuclear Weapon-Free Zone, and the Mongolian Nuclear Weapon-Free Zone. Neighboring the region is the Central Asian Nuclear Weapon-Free Zone.

United States and the then Soviet Union were particularly concerned about the potential spread of enrichment and reprocessing capability, the NPT does not refer to specific technologies. When the treaty was negotiated it was believed proliferation risk would be limited because only the nuclear-weapon states and a small number of other advanced industrialized states would have enrichment and reprocessing capabilities. It was envisaged that technology holders would provide fuel cycle services to other states, removing any need for these other states to establish such capabilities themselves.

With the benefit of hindsight, it can be seen that the problem of the spread of enrichment and reprocessing was not well anticipated in the drafting of the NPT. There are two aspects to this problem: the ability of further states to obtain these technologies was underestimated, and too much reliance was placed on the ability of IAEA safeguards to provide timely warning in the event of misuse of these technologies.

It is now known that during the NPT negotiations UK officials warned their US counterparts that centrifuge enrichment presented a serious risk to the NPT's objectives. Unfortunately, this warning was not heeded, and the language in the treaty draft was not amended to address the problem. This warning proved prescient, as there has been a gradual spread of proliferation capabilities, particularly centrifuge enrichment technology, accelerated by black market activities, notably involving the Pakistan-based AQ Khan network. The relative ease of concealing centrifuge plants, and the potential speed of break-out, mean that in certain diversion scenarios, discussed below, adequate warning time cannot be assured.

Reprocessing raises timeliness issues that can be even more acute. Where stocks of separated plutonium are held, there is a real possibility that if a state diverts plutonium and has made the necessary preparations in advance, it could fabricate the plutonium into nuclear weapons well before effective international intervention is possible.

Today, as shown in Table 1, in addition to the five nuclear-weapon states and the other four nuclear-armed states, there are at least six non-nuclear-weapon states currently operating enrichment plants, and one (Japan) with reprocessing capability.

Table 1: States with Demonstrated Enrichment and/or Reprocessing Capability (Past or Current)[3]

Nuclear-weapon states	**Non-NPT nuclear-armed states**	**Non-nuclear-weapon states**	
These states have both enrichment and reprocessing capabilities		**Enrichment capability**	**Reprocessing capability**
United States Russia United Kingdom France China	India Pakistan DPRK Israel	Argentina Brazil Germany Iran Japan Netherlands	Japan
		Australia *South Africa*	*Belgium* *Germany* *Italy*

Note: For the non-nuclear-weapon states shown in italics the enrichment and/or reprocessing activity is no longer current. In some cases, these activities were only small-scale.

Factors Relating to Proliferation Risk

Broadly speaking the possibility of a state deciding to pursue nuclear weapons will be influenced by three factors: capability, motivation, and the barriers and disincentives to proliferation.

It can be debated whether motivation or capability comes first. They may be closely related and their sequencing can differ from case to case. The typical image of proliferation—exemplified by Iraq—involves a state deciding to pursue nuclear weapons and then setting out to develop the necessary technical capabilities. In this case motivation precedes capability. When a state develops enrichment or reprocessing capabilities in secret, it is a clear sign of proliferation intent.

The situation is not so clear, however, when a state develops such capabilities openly under IAEA safeguards. The state may be deliberately establishing a nuclear weapon option—in this case motivation still precedes capability, but the state's intention is not obvious. On the other hand, the state at that time may be genuinely committed against acquiring nuclear weapons. The problem is, once the state has the relevant capabilities it thereby has a nuclear weapon option if circumstances

[3] Iraq is not included because at the time its enrichment program was terminated, its output was small.

change—what is unthinkable today might be considered a necessity tomorrow. In such a case capability could influence motivation.

Nuclear weapon capability

The capability to develop nuclear weapons can be broken down into a number of key elements:

1. Production of fissile material
2. Nuclear weaponization
3. Deployment of nuclear weapons

1. Production of fissile material: First and foremost a state considering pursuit of nuclear weapons requires the capability to produce fissile materials[4]—HEU or separated plutonium. This requires the state to have enrichment or reprocessing facilities. Accordingly, when a state without enrichment or reprocessing seeks to establish these capabilities it is inevitable there will be international questioning, if not concern, about the state's intentions. Export controls applied by members of the NSG discourage, but do not exclude, such projects.

Enrichment: In the case of uranium enrichment, no state planning to produce HEU is going to admit to this. Globally, production of HEU for civilian use has ceased (with some very limited exceptions), so any production of HEU would immediately attract international attention. Accordingly, a state developing enrichment capability would claim to be doing so solely for producing low enriched uranium (LEU) reactor fuel.[5] However, there is no inherent technical barrier to using any of the currently established enrichment technologies to produce HEU.

Centrifuge facilities in particular can be readily adapted for producing HEU. Time would be required to reconfigure a facility to produce HEU, thus providing some warning of the state's intentions. However, this warning time could be fairly short, a matter of weeks or even days. If the state has the capability to manufacture centrifuges it is more likely to establish clandestine facilities for high enrichment, thus avoiding the warning that would result if it was seen modifying declared facilities.

[4] For safeguards purposes the IAEA uses the term *unirradiated direct-use material* instead of *fissile material*.
[5] LEU is typically in the range three to five percent U-235.

While LEU cannot be used directly in weapons, LEU can be used as feed for higher enrichment, substantially shortening the time to produce HEU.[6] Hence stockpiling of LEU in bulk form (especially enriched uranium hexafluoride–UF_6) may have a proliferation significance.

Reprocessing: In terms of proliferation risk, reprocessing is more problematic than enrichment because in normal operation the product of a reprocessing plant is weapon-usable material.[7] Further, in the normal operation of reprocessing plants it is usual to have substantial quantities of separated plutonium on hand, providing the opportunity for rapid diversion to weapon production. Considering that the IAEA's *significant quantity*[8] for plutonium is only 8 kilograms, a plutonium inventory of just one tonne—modest by industry standards—is sufficient for well over 100 weapons.

Other means of acquisition: While the focus here is on states' establishing the capability to *produce* fissile material, it should not be overlooked that fissile material may also be acquired by *international transfer*: either by legitimate imports, e.g., research reactor fuel; critical assembly fuel or MOX[9] fuel; or by illicit procurement, e.g., purchase on the black market or by theft or seizure. While generally the quantity of fissile material that could be imported is relatively limited, in the case of plutonium in the form of MOX the quantity could be sufficient for a small nuclear arsenal.

2. Nuclear weaponization: *Weaponization* is a shorthand term for the range of activities, additional to acquisition of fissile material, necessary to produce a nuclear weapon. These include nuclear weapon design and associated modelling and calculations, high-explosive lenses and

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[6] Almost ninety percent of the enrichment effort to produce weapon grade HEU (ninety percent U-235) is expended in reaching five percent U-235 (the upper end of typical LEU). To reach ninety percent enrichment, starting with five percent enriched LEU, requires much less enrichment effort compared with starting with natural uranium; in other words, this can be achieved with a much smaller plant.

7 With some reprocessing processes the output is a plutonium/uranium mix, rather than pure plutonium, but the plutonium is not difficult to separate. Historically the states with nuclear weapons produced low burn-up plutonium (predominantly comprising the isotope Pu-239) for this purpose, but in principle almost all plutonium is considered to be weapon-usable.

[8] The significant quantity (SQ) is the quantity for which the possibility of manufacturing a nuclear explosive device cannot be excluded.

[9] MOX comprises a mixture of uranium and plutonium oxides.

implosion testing, specialised high-energy electrical components, high-flux neutron generators, and design and testing of warhead re-entry vehicles.

In contrast to nuclear materials and facilities—where IAEA safeguards provide a well-established system for verifying peaceful use—in the case of other items and materials of possible application to nuclear weaponization it is much more difficult to monitor states' activities,[10] and many of these could be pursued in secret. Further, many of these activities, items, and materials are *dual-use*, that is, taken in isolation they do not necessarily indicate an intention to manufacture a nuclear weapon. Some, but not all, involve items on the NSG dual-use list.[11] The purpose of a single dual-use activity may be ambiguous, but a combination of such activities may more clearly indicate the existence of a nuclear weapon program.

In assessing the significance of apparent weaponization activities, an essential question is whether the state is known to have fissile material or the capability to produce it. This in itself, however, is not necessarily conclusive. It is possible that detection of weaponization activities may be the first indicator that a state already has an undeclared (and so far, undetected) program to produce fissile material or may indicate that a state intends to divert safeguarded fissile material in the future.

3. Deployment of nuclear weapons: The principal capability issue here relates to nuclear-capable delivery systems. While in theory nuclear weapons could be delivered by unconventional means, e.g., truck, fishing boat, or shipping container, in reality these would be of interest only to terrorists. A state requires credible nuclear deterrence based on a delivery system that will perform reliably and has a high probability of avoiding interception. In view of the vulnerability of aircraft, ballistic missiles are the preferred delivery method. Hence, discovery that a state has a ballistic missile program will be a warning sign. Given the substantial costs and accuracy limits of ballistic missiles, development of such missiles may well indicate an intention to deploy highly destructive (i.e., nuclear) warheads.

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[10] Prohibitions and monitoring arrangements for certain weaponization-related activities were included in the Iran JCPOA (Joint Comprehensive Plan of Action) as Section T of Annex I.

[11] IAEA, "Communication Received from the Permanent Mission of Kazakhstan to the International Atomic Energy Agency regarding Certain Member States' Guidelines for Transfers of Nuclear-related Dual-use Equipment, Materials, Software and Related Technology," Information Circular INFCIRC/254/Rev.11/Part 2a, 18 October 2019, https://www.iaea.org/sites/default/files/publications/documents/infcircs/1978/infcirc254r11p2.pdf

An indication of relevant capabilities is given by the *Guidelines for Sensitive Missile-Relevant Transfers* under the Missile Technology Control Regime, that is, missiles with a range exceeding 300 kilometers and a payload exceeding 500 kilograms. A state developing missiles exceeding these parameters is not necessarily seeking a nuclear capability (for example, it may say it is engaged in space research), but such development will be grounds for suspicion, especially where other indicators are present, such as apparent weaponization activities, safeguards violations, and so on.

Other aspects of nuclear weapon deployment include organization and training of specialist military forces, development and promulgation of nuclear doctrine concerning the use of nuclear weapons, and establishment of command and control systems for nuclear weapons.

Nuclear weaponization and nuclear delivery and other deployment matters are beyond the scope of this paper, but these can give rise to indicators and observables which could have implications relevant to the fuel cycle, for example, indicating that a state's interest in the fuel cycle may be dual-purpose.

Motivation to acquire nuclear weapons

Motivation is the result of a stimulus or incentive that influences a government to act in a certain way. There are several reasons why a government might decide to pursue nuclear weapons, including its perception of threats and the need for a military deterrent, the desire to exert influence over other states, and notions of prestige and national pride. While these are political sentiments, they can be given tangible form discernible to other governments and observers through statements made and actions taken.

The principal indicator for a state's motivation is its *strategic environment*. Relevant questions include:

- Whether the state is located in a *region of tension*;
- Whether it is, or believes itself to be, under military, economic, cultural, or religious threat;
- Whether it is involved in military or political confrontation with other states.

The clearest example of a region of tension is the Middle East, and it is no coincidence that of the six safeguards non-compliance cases that have occurred to date, four have involved states in or closely associated with the Middle East.[12] The Asia-Pacific region contains two areas that can be considered regions of tension: South Asia and North Asia, particularly the Korean Peninsula.

Motivation can be seen at play in the Korean Peninsula. First there is the action of the DPRK in developing nuclear weapons. The DPRK maintains it did this in response to threats by the United States—hostile statements, sanctions, military exercises, and the ongoing armistice (that is, the absence of a peace settlement) have all been contributing factors. In response to the DPRK's actions, many people in the ROK and Japan have argued for these states to acquire their own nuclear deterrent. This situation illustrates two points:

- Acquiring nuclear arms does not improve a state's security, especially if it motivates neighbors to do the same.
- Military alliances can be an important factor affecting motivation to pursue nuclear weapons. As long as the ROK and Japan have confidence in their alliances with the United States their motivation to pursue nuclear weapons will be reduced, and *vice versa*—if confidence in the alliance is lacking, an independent nuclear deterrent might seem more necessary.

Not only can alliances reduce the motivation to pursue nuclear weapons, oversight by the alliance partner (the United States) will reduce the opportunity to do so, as was seen in US interventions against proposed transfers of proliferation-sensitive nuclear technologies in the 1970s.

Barriers and disincentives to proliferation

Proliferation barriers can take two forms, technical or political (or institutional).

***Technical barriers*:** These could include design features in nuclear facilities that can reduce or even eliminate the risk of proliferation. In the case of uranium enrichment this does not seem practicable—there is no technical barrier to using any of the currently established enrichment technologies to produce HEU.

[12] Iraq, Iran, Libya and Syria.

Technical barriers may be possible at the back-end of the fuel cycle. Here the fundamental question is, is it essential to recycle plutonium? In the case of *thermal reactors* (such as light water reactors) plutonium recycle is not necessary from a technical standpoint and cannot be justified economically (discussed further below). Proliferation risk can be avoided simply by not reprocessing.[13]

Plutonium recycle is required only if fast breeder reactors (FBRs) become economically viable. Where plutonium recycle technologies are developed, proliferation resistance and safeguards by design should be built in. This principle has been adopted by the Generation IV International Forum.[14] Consistent with this approach, recycle technologies that do not produce plutonium in readily accessible form are preferred to reduce the risk of proliferation and also sub-national theft. Concepts include liquid fuelled reactors (such as molten salt fast reactors) with online reprocessing (where the reprocessing unit is connected to the reactor, unwanted materials are removed and the plutonium-bearing stream is recycled directly back to the reactor). Another is pyro-processing, currently the subject of a joint study by the United States and the ROK.[15]

With pyro-processing, plutonium is not fully separated but remains in a highly radioactive mix with uranium, actinides, and fission products. Proponents maintain the process cannot produce pure plutonium and is therefore proliferation-resistant. US experts dispute this, and proliferation-resistance is a major aspect of the US–ROK joint study. Even if pyro-processing does not fully separate plutonium, it could still have proliferation significance by making the task of the proliferator easier. This is because the product of pyro-processing represents a very substantial quantitative reduction (by a factor of ten to twenty-five) compared with spent fuel at the start of the process, allowing the proliferator to use a much smaller scale plutonium separation facility than would otherwise be required.

***Political and institutional barriers and disincentives*:** These take several forms. Considering that all states that currently do not have nuclear weapons are non-nuclear-weapon states parties to the

[13] J. Carlson, L. Spector, M. Pomper, *The Other Fissile Material: Strengthening National and International Plutonium Management Approaches*, CNS, December 2018, https://nonproliferation.org/wp-content/uploads/2018/12/op42-the-other-fissile-material.pdf

[14] The Generation IV International Forum, https://www.gen-4.org/gif/

[15] The US-ROK Joint Fuel Cycle Study is outlined at page 52 of the 2015 US-ROK nuclear cooperation agreement, https://irp.fas.org/news/2015/06/123rok.pdf

NPT, and the development of nuclear weapons by such a state would violate the NPT, the principal deterrent to a would-be proliferator is the probability of detection by IAEA safeguards and the likely consequences of detection. These include Security Council sanctions and the risk of intervention, including military action, by states that consider themselves threatened. The proliferating state will be gambling that it can maintain secrecy long enough that by the time it is discovered it is too late for other states to intervene. If the state succeeds in acquiring nuclear weapons, however, it faces international sanctions that are likely to have a profound impact on its economy, and it will become an international pariah.

With regard to disincentives, one would hope the state is capable of a rigorous analysis of the dangers of proliferating. A state with nuclear weapons becomes a nuclear target. It is at risk of nuclear war, whether by deliberate actions or by mistake, miscalculation, or unauthorized actions, either by its own forces or by an adversary. Far from guaranteeing its security, possession of nuclear weapons will be an ongoing source of danger.

From a longer-term perspective, all states, even those outside the NPT, benefit from an effective non-proliferation regime that minimizes the number of states with nuclear weapons. There is no doubt that the more states have nuclear weapons, the more likely they will be used. The risk for a proliferator is that its actions will motivate others to do the same—so the "advantage" of acquiring nuclear weapons will be temporary. In due course the state's adversaries will also be nuclear-armed, so its security situation will be much worse than before.

Institutional barriers to proliferation include export controls that aim to prevent access to sensitive technologies, equipment, and materials. On the positive side, incentives to maintain good non-proliferation standing include access to nuclear energy technology, fuel, and cooperation, as well as wider economical and technical benefits.

More intrusive safeguards, monitoring, and transparency measures could be introduced for states that have enrichment or reprocessing programs, but in case of misuse there can be no absolute assurance of timely warning, or that effective intervention will be possible. The most effective institutional barrier is to avoid national enrichment and reprocessing programs. National programs can be obviated by multilateral arrangements, such as fuel supply guarantees and multilateral control of proliferation-sensitive facilities. These matters are discussed in section six of this paper.

Nuclear Latency and Nuclear Hedging

Considerations of nuclear capability and motivation come together in the case of a state that has nuclear latency. Nuclear latency refers to the situation where a state has established, under a peaceful nuclear program, dual-use capabilities that could be used to produce nuclear weapons. The concept of nuclear latency applies to those non-nuclear-weapon states that have current capabilities in enrichment or reprocessing (there are six such states, see Table 1). It might also apply to those states that had such capability in the past, depending on how quickly the capability could be re-established. In addition, the concept is relevant to states seeking to develop enrichment or reprocessing capabilities as part of their nuclear power programs.

Nuclear latency might be inadvertent, e.g., while a state with uranium enrichment and/or reprocessing capabilities thereby has the basic capability to produce fissile material for nuclear weapons, it may well have (at least in foreseeable circumstances) no intention of doing so. On the other hand, nuclear latency could also be deliberate—a state could establish enrichment or reprocessing capabilities with an eye to having an essential component for a nuclear weapon option should its strategic circumstances change at some future time.

If nuclear latency might be an unintended consequence of having certain technologies, nuclear hedging refers to a deliberate national strategy of establishing the option of acquiring nuclear weapons within a relatively short time frame. Compared with latency, nuclear hedging has a much shorter time horizon, ranging from several weeks to at most a few years. The shorter time frame reflects the level of preparation—hedging implies the state not only has fissile material production capacity but is also undertaking at least some weaponization activities and developing or acquiring nuclear-capable delivery systems.

Some of the indicators which could point to an interest in nuclear weapons were outlined above. However, some of these indicators will be difficult to detect—so an apparent absence of indicators is not necessarily reassuring—and even if detected, the purpose could be ambiguous. The only visible indicator that a state is hedging may well be that it is pursuing an enrichment or reprocessing program that lacks a technically and economically convincing rationale.

Energy security is a justification for fuel cycle capabilities. States that pursue enrichment and reprocessing commonly cite energy security or energy independence as a rationale. Looking first at uranium enrichment, this is technologically demanding and is strongly affected by economies of scale. The commercial enrichment market is dominated by a small number of suppliers, principally Russia and Urenco (Germany, Netherlands, and the United Kingdom). The United States and France were major suppliers but the technology they used (gaseous diffusion) became uncompetitive, and today they both use Urenco technology (centrifuges). As Table 1 shows, a handful of states have developed national enrichment programs, but the great majority of states with nuclear power programs buy enrichment services on the international market.

For some years the international market has been in substantial over-supply, and enrichment prices are very low. Global annual enrichment capacity is 66.7 million SWU[16] compared to global annual demand of 57.5 million SWU. Russia's capacity is 28.7 million SWU and Urenco's is 14.9 million SWU. For some time, it is likely that growth in global demand will be offset by increases in China's capacity (currently 10.7 million SWU). In these circumstances there is no convincing economic case for additional states to develop uranium enrichment capacity. Concerns about security of supply, if any, can be addressed by appropriate fuel supply assurances or by buying into an established operation.

Historically, security of supply has also been cited as a rationale for reprocessing. In the early years of the nuclear industry, it was thought that uranium was scarce and would become increasingly expensive. In response, the concept of fast breeder reactors (FBRs) was developed. FBRs would maximise production of energy from uranium through separation and recycle of plutonium. Doing this necessitates reprocessing. Plutonium was seen as a national energy resource: recycling would reduce dependence on imported uranium and enrichment services.

The historic rationales for reprocessing and use of plutonium fuels no longer apply. It is clear that plutonium fuels are not required to ensure the sustainability or reliability of nuclear energy. Uranium is abundant and low-cost. Reprocessing is vastly uneconomic for light water reactors, the

[16] SWU refers to Separative Work Units, a metric of isotopic separation capacity. Given in full the metric is SWU per year (SWU/yr), but in this paper it is abbreviated to "SWU" for convenience.

predominant type in use today: plutonium is more expensive than use even of very high-cost uranium (including extraction of uranium from seawater).

The high cost of reprocessing is reflected in the massive surplus of plutonium. As at the end of 2018 (the most recent figures available) civilian stockpiles of separated plutonium (349 tonnes) greatly exceeded the quantities of plutonium in military programs (220 tonnes). Although the international Guidelines for the Management of Plutonium highlight the importance of balancing plutonium supply and demand, lack of demand has prevented this. The lack of a use for plutonium has led to the United Kingdom closing its reprocessing operations.

Currently only Russia and India are actively pursuing development and deployment of FBRs. Japan and France have terminated their FBR programs. France's Atomic and Alternative Energies Commission (CEA) has announced that in the current energy market the industrial development of fourth-generation reactors is not planned before the second half of this century.

Most states with nuclear power programs have either decided to proceed with the once-through fuel cycle, where spent fuel will be disposed of as a waste material or have adopted a wait-and-see attitude. From a technical perspective, most spent fuel can be stored for many decades, so there is no pressing reason to commit in the near term to final disposal or to recycle.

With regard to energy security, the main challenge for nuclear power is not security of fuel supply but public and political confidence, which is most impacted upon by safety concerns. Rather than pursuit of complex nuclear technologies in the name of energy independence, energy security is best served by pursuing energy diversity and, in the nuclear sector, by a total commitment to safety in all aspects—design and construction, facility upgrades, and operations.

A problem of scale

The fundamental issue is that the fissile material production capacity required for a nuclear weapon program is very small compared with commercial-scale operations. Even a modest industrial capacity can provide a substantial weapon capability and a short breakout time.

In the case of uranium enrichment, the capacity required to produce sufficient LEU for the annual fuel requirements of just one typical light water reactor is around 110,000 SWU. A "small" commercial plant is two or three million SWU. The capacity required to produce sufficient HEU for one nuclear weapon in one year is only 5,000 SWU (or less than 1,000 SWU if using LEU feed).

In the case of reprocessing, a modern reprocessing plant can have an annual throughput of 800 tonnes of spent fuel, separating about 8 tonnes of plutonium (this is the scale of Japan's Rokkasho plant and the French plant proposed for China). An output of 8 tonnes of plutonium is 1,000 times the IAEA significant quantity figure of 8 kilograms.

Because it is difficult to tell what the state's intentions are, or to predict what they may be at some future time, from a non-proliferation perspective the fewer national enrichment and reprocessing programs there are the better, and vice versa, the more widespread these capabilities become, the greater the risk of proliferation, now or in the future. If a number of states decided to pursue these capabilities there is the risk of virtual arms races, undermining international trust and destabilising the non-proliferation regime.

Prospective Fuel Cycle Developments in the Asia-Pacific Region

Leaving aside states with nuclear weapons (China, India, Pakistan, and the DPRK), currently Japan is the only state in the region that has enrichment and reprocessing activities. The ROK is undertaking research on a type of reprocessing, pyro-processing, and has shown interest in uranium enrichment. Australia has had uranium enrichment research and development projects but has no current or planned activity in this area.

Japan has both enrichment and reprocessing. Japan's enrichment capacity, based on centrifuge technology, is relatively small, 75,000 SWU, about two-thirds of what is required to meet the annual fuel requirements of a single typical light water reactor. Notwithstanding the global oversupply, there are plans to increase Japan's enrichment capacity twenty-fold, to 1.5 million SWU.

Japan has been engaged in reprocessing since the 1970s. The first reprocessing plant, at Tokai-mura, was closed in 2006, but Japan proceeded with a much larger plant at Rokkasho—annual capacity 800 tonnes of spent fuel, output around 8 tonnes of plutonium. Rokkasho is ready to commence operations but start-up has been deferred several times, currently until 2022. Meanwhile, Japan has accumulated almost 46 tonnes of separated plutonium, 9 tonnes in Japan and the balance held in the United Kingdom and France. It makes no sense to add to this very substantial stockpile.

It is hoped Japan will make the current moratorium on Rokkasho permanent, or at least extend it until such time, if ever, that there is a genuine need for the plutonium. Although Japan has a longstanding and strongly held commitment against nuclear weapons, the threat of DPRK nuclear weapons has prompted calls in Japan to maintain fuel cycle capabilities to ensure a nuclear weapon option.[17] This has led to some unease about the proliferation potential of the Rokkasho project.

In **the ROK** the nuclear research establishment also sees FBRs as important for the future and, to this end, has been researching pyro-processing for some time. Pyro-processing became an issue in the renewal of the US-ROK nuclear cooperation agreement in 2015. The ROK sought US consent to reprocessing and recognition of a right to enrich. In response to ROK concerns about fuel security, the renewed agreement provides US nuclear fuel supply assurances. The agreement refers to possible enrichment or reprocessing in the ROK, but this would require the further agreement of the parties. The ROK and the United States are conducting a Joint Fuel Cycle Study on spent fuel management, including assessment of the viability of pyro-processing and safeguards and proliferation aspects of this technology. This study is expected to be completed in 2021.

The possibility of enrichment and/or reprocessing in the ROK is viewed with concern in the region and in Washington, and in the ROK itself.[18] Such activities would be disruptive for efforts to negotiate a denuclearization process with the DPRK. Concerns are exacerbated by calls in the

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[17] See for example, the remarks by Japan's former defense minister, Satoshi Morimoto, prior to his appointment,which was reported in the Japan Times on 6 September 2012: https://web.archive.org/web/20121013202153/www.japantimes.co.jp/text/nn20120906b4.html

[18] E. Lim, *South Korea's Nuclear Dilemmas*, Journal for Peace and Nuclear Disarmament, Volume 2, 2019, https://www.tandfonline.com/doi/full/10.1080/25751654.2019.1585585

ROK for an independent nuclear deterrent and the high levels of support for this (sixty percent or more) shown in public opinion polling.[19]

Overall, for both the ROK and Japan (and also China) there is a strong argument for deferring the development of plutonium-recycle technologies until it can be demonstrated that they are actually needed. If or when such development does proceed, it should be conducted under arrangements that fully address proliferation concerns.

Australia has had two R&D projects on uranium enrichment: a centrifuge project from the mid-1960s to the mid-1980s, and a laser-based project, SILEX, from the early 1990s to 2007 when the project was transferred to the United States for further development. In addition, there was a private sector study into the establishment of an enrichment industry in the 1970s. Initially this looked at the Australian centrifuge technology but finally settled on Urenco technology. Eventually the study was terminated for commercial reasons and also because of a change of government. The basis for these various projects was the possibility for Australia to value-add on its substantial uranium exports.

Reflecting anti-nuclear sentiment, in 1999 legislation was passed prohibiting the licensing of fuel cycle activities in Australia, including uranium enrichment. This prohibition remains in place today.

The possibility of Australia enriching uranium for export continues to be raised from time to time and was thoroughly examined by the South Australian Nuclear Fuel Cycle Royal Commission in 2015–16.[20] The Commission concluded that with an oversupplied and uncertain global market there was no opportunity for commercial development of uranium enrichment in Australia for the foreseeable future. If enrichment were pursued, the Commission recommended this should be on a multilateral basis with the participation of partner countries to address the issue of nuclear latency. In a submission to the Commission the national government expressed support for the principle of multilateral control of sensitive stages of the fuel cycle. The Commission

[19] Rachel Oswald, 'Southern Discomfort', *Pulitzer Center*, 10 April 2018, https://pulitzercenter.org/stories/southern-discomfort

[20] Nuclear Fuel Cycle Royal Commission Consultation and Response Agency, 'Nuclear State-Wide Engagement' (Royal Commission, 2016), https://nuclear.yoursay.sa.gov.au/the-report The author was a member of the Commission's Expert Advisory Committee.

recommended that the South Australian government seek repeal of the national prohibition against fuel cycle activities so any proposals that arise could be considered further, but because of the poor economic prospects the government did not adopt this recommendation.

The Commission's principal recommendation was in favour of establishing an international spent fuel repository in South Australia. Bipartisan consensus was lacking for this to proceed. In the absence of bipartisan consensus, no nuclear developments are likely to proceed in Australia.[21]

Taiwan As noted earlier, Taiwan sought reprocessing capabilities in the 1970s. The 1974 nuclear cooperation agreement between the United States and the governing authorities on Taiwan contained the standard provision proscribing enrichment or reprocessing without US prior consent. When the agreement was renewed in 2014 Taiwan forswore enrichment and reprocessing, what is known in the United States as the "gold standard" for nuclear cooperation agreements.[22]

Vietnam had an ambitious plan to build up to ten nuclear power units by 2030 and negotiated project agreements with Russia and Japan. It concluded a nuclear cooperation agreement with the United States in 2014. The United States pressed Vietnam to forswear enrichment and reprocessing, but Vietnam declined to do this and instead expressed in the agreement its intent to rely on existing international markets for nuclear fuel services, rather than acquiring sensitive nuclear technologies. In 2016 Vietnam decided to postpone both the Russian and Japanese reactor projects indefinitely due to economic conditions, and the future of Vietnam's nuclear power program is uncertain.

Other Southeast Asian states that were planning nuclear power programs but deferred them for economic and other reasons include:

[21] On 15 September 2021 Australia, the US and the UK announced a proposal to provide Australia with nuclear-powered submarines. This proposal does not involve Australia producing nuclear fuel. See the author's commentary, "AUKUS Nuclear-Powered Submarine Deal – Non-proliferation Aspects", https://www.apln.network/analysis/commentaries/aukus-nuclear-powered-submarine-deal-non-proliferation-aspects

[22] The "gold standard" first appeared in the 2009 US-United Arab Emirates agreement.

Indonesia The 2017 National Energy General Plan to 2050 excludes major nuclear capacity in favour of increases in oil, gas, and renewables and a focus on small-scale nuclear plants.[23]

Malaysia the year 2030 had been suggested as the earliest date for construction of a nuclear power plant, but more recently the Prime Minister has ruled out use of nuclear energy.[24]

Thailand The current Power Development Plan, for the period to 2037, has no provision for nuclear energy.[25]

In addition, the **Philippines**, which had a power reactor in the 1980s that was never started, is reported to be considering nuclear power again, but as yet no decisions have been taken.[26]

In South Asia, **Bangladesh** has two Russian-supplied power reactors under construction, scheduled for completion in 2023–2024 and 2024–2025. Russia will supply the fuel and take back spent fuel.[27]

None of these states has any plans for pursuing enrichment or reprocessing capabilities.

Finally, mention should be made of **Myanmar**. In the period 2000–2011 the military regime's links with the DPRK led to concerns about a possible nuclear weapon program. Following the establishment of a civilian government in 2011, Myanmar affirmed its commitment to non-proliferation. Myanmar signed a safeguards Additional Protocol in 2013, though this has not yet been ratified. Myanmar is engaging with the IAEA and participates in the Asia-Pacific Safeguards Network.

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[23] F. Todd, "Analysing the Development of Nuclear Power across Southeast Asia," Nuclear Engineering International, August 5, 2019, https://www.nsenergybusiness.com/features/development-nuclear-power-southeast-asia/

[24] Nor Ain Mohamed Radhi, "Malaysia Won't Use Nuclear Power, Says PM," *NST Online*, February 10, 2020, https://www.nst.com.my/news/government-public-policy/2020/02/564295/malaysia-wont-use-nuclear-power-says-pm

[25] "Power Plan Backed along wIth 2 Plants," *The Nation*, January 24, 2019, http://www.nationthailand.com/Economy/30362896

[26] Sustainability Times, "The Philippines Is Eyeing Nuclear Power as a Green Option," *Sustainability Times* (blog), March 13, 2020, https://www.sustainability-times.com/low-carbon-energy/the-philippines-is-eyeing-nuclear-power-as-a-green-option/.

[27] "Nuclear Power in Bangladesh - World Nuclear Association," Nuclear Power in Bangladesh, accessed October 27, 2021, https://www.world-nuclear.org/information-library/country-profiles/countries-a-f/bangladesh.aspx, accessed 15 April 2020.

Conclusion - Minimising Proliferation Risk

Horizontal proliferation is usually thought of in terms of clandestine nuclear programs. Actions taken to counter such programs have included strengthening IAEA safeguards and export controls. The risks from nuclear latency—states developing proliferation capabilities openly as part of their safeguarded nuclear programs—are recognized, but avoiding latency has not attracted the same level of attention as clandestine programs.

The NSG Guidelines[28] ask suppliers of enrichment or reprocessing facilities, equipment, or technology to encourage recipients to accept, as an alternative to national plants, supplier involvement and/or other appropriate multinational participation in resulting facilities. The Guidelines also ask suppliers to promote multinational regional fuel cycle centres. These Guidelines, however, do not amount to a commitment against further national projects and, of course, they are applicable only where transfers are involved. They do not apply to wholly indigenous projects.

The pursuit of national enrichment and reprocessing programs highlights the latency/hedging dilemma. While every state wants energy security—to which nuclear energy could make an important contribution—this does not necessitate *every* state, or even *many* states, having national programs in proliferation-sensitive technologies. States need to see energy security, not in narrow technology terms (pursuit of fuel cycle capabilities), but in a much wider context. Paradoxically, having such programs could be counterproductive to a state's broader security interests, either directly, due to the threat perceptions and reactions of other states, or more generally through a weakening of the non-proliferation regime. A large part of addressing the latency/hedging problem will be to help states to understand and think constructively about this national security paradox.

The only sure way to address the issues of nuclear latency and hedging is to reach international acceptance that proliferation-sensitive stages of the fuel cycle should be under multilateral rather than national control. A new international framework for the nuclear fuel cycle is needed, emphasizing international collaboration in place of national programs. Key elements in the new

[28] NSG Guidelines, Part I, paragraph 6(e).

framework would include multinational fuel cycle centers, international fuel supply guarantees, and fuel leasing.

Multinational approaches are not an unrealistic aspiration. Already there are practical precedents with important characteristics that can be built upon in future models, including:

- Urenco, the European enrichment group, where there is a treaty providing for mutual oversight of facility operations by the treaty parties, as well as separation between facility operators and technology design/manufacture (in effect a *black box* arrangement).
- The International Uranium Enrichment Centre (IUEC), Russia, which provides enrichment customers with supply guarantees overseen by the IAEA, and also the opportunity for equity participation in the project.
- The IAEA LEU Bank, operated by Kazakhstan on the IAEA's behalf.
- A form of fuel leasing is provided by Rosatom (Russia), which supplies fuel assemblies and takes back spent fuel from a number of customers.

The key factor with sensitive facilities is multinational, rather than wholly national, control. Multinational participation provides transparency of facility operations and inhibits possible takeover by the host state, especially where this would violate treaties. An additional inhibitor is supply of technology under black box arrangements, where this is practicable. This precludes clandestine replication, and builds delays into any misuse scenario, providing greater opportunity for intervention.

If in the future the viability of plutonium recycle is established, an appropriate model might be nuclear "islands" in which fast reactors and associated recycle processing facilities are physically co-located under multinational control.

Fuel banks need not be physical, as with the IAEA LEU Bank in Kazakhstan, but could be *virtual*, as with the fuel supply guarantee provided by the IUEC. Under multinational arrangements virtual fallback supply could be provided by a number of suppliers.[29]

[29]. For more on multinational arrangements see *Multilateral Approaches to the Nuclear Fuel Cycle*, IAEA, 2005, http://www-pub.iaea.org/books/IAEABooks/7281/Multilateral-Approaches-to-the-Nuclear-Fuel-Cycle and J.

Multinational approaches should not be looked at in isolation but considered in the context of possible further complementary non-proliferation and confidence-building mechanisms, such as enhanced transparency, nuclear weapon-free zones, and regional safeguards arrangements.

In current circumstances there is no urgency to proceed with new or deferred enrichment or reprocessing projects. As discussed, the global enrichment market is substantially over-supplied, and there is no sound technical or economic rationale for reprocessing unless the viability of fast reactors is established, which is by no means assured and in any case is decades away. Accordingly, a constructive approach would be to defer any current plans and allow time to develop multinational, including regional, solutions. To this end, regional studies could be initiated on the concepts discussed here.

While multinational approaches are usually framed in the context of the risk of horizontal proliferation—the focus of this paper—this is also an issue for disarmament. In the future the potential for rapid break-out from arms control and disarmament commitments will be just as great a concern as the potential for break-out from non-proliferation commitments by nuclear weapons states using a residual surge capacity to reverse direction. The parties to arms control and disarmament negotiations can be expected to seek appropriate confidence-building measures to cover ongoing fuel cycle activities. Accordingly, there could be interest in adapting approaches developed for the ROK, Japan, and other non-nuclear-weapon states to also apply in the future to China, India, and Pakistan.[30]

Clearly gaining support for multinationalization of proliferation-sensitive stages of the fuel cycle will be challenging. However, achieving a future free from the danger of nuclear war requires a change in current mindsets, from an emphasis on national fuel cycle programs to new approaches based on the common interests of non-proliferation, nuclear disarmament, energy security, and strengthened international collaboration.

Carlson, *Multinational Approaches to the Nuclear Fuel Cycle*, in Routledge Handbook of Nuclear Proliferation and Policy, J. Pilat and N. Busch eds, Oxford, 2015.

[30] Of course the issue is equally applicable to the United States, Russia, the United Kingdom, France, and Israel.