# ADDRESSING PROLIFERATION CHALLENGES FROM THE SPREAD OF URANIUM ENRICHMENT CAPABILITY

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*This paper presents the personal views of the author and not necessarily those of the Australian Government.*

## Abstract

From the outset of the nuclear era it was recognised that an effective non-proliferation regime depends on maintaining effective control over sensitive nuclear technologies, i.e. uranium enrichment and reprocessing. Because these technologies can be used to produce fissile material for nuclear weapons, their unconstrained spread, even for ostensibly civil purposes, would work against non-proliferation objectives – if nothing else, undermining confidence about states' future intentions.

This paper focuses on uranium enrichment issues. In light of recent developments – including the discovery of an extensive black market in enrichment technology and, closely related, Iran's pursuit of a uranium enrichment program – the need to limit the spread of enrichment capability is assuming increasing urgency. This presents both technical and political challenges.

A number of proposals and initiatives have been advanced to address this issue. To date these have been aimed primarily at limiting, or proscribing, transfers of enrichment technology, or specialised components and materials. However, these approaches do not fully address other dimensions of the problem: illicit acquisition of enrichment technology, and development of indigenous enrichment technology. A way is needed to assess the international acceptability of enrichment projects regardless of whether they involve transfers of controlled items.

A "one size fits all" approach to countering the spread of enrichment capability is unlikely to gain international acceptance. Rather, an approach is required that reflects a careful analysis of the issues and risk factors. This paper discusses relevant considerations.

## 1. INTRODUCTION

An effective non-proliferation regime depends on maintaining effective control over sensitive nuclear technologies (SNT), i.e. uranium enrichment and reprocessing. Because these technologies can be used to produce fissile material for nuclear weapons, their unconstrained spread, even for ostensibly civil purposes, would work counter to non-proliferation objectives. If nothing else, possession of these technologies could provide the basis of a latent nuclear weapon capability, thus undermining confidence about states' future intentions.

This paper focuses on uranium enrichment issues. As regards reprocessing, the development of fast reactors and advanced spent fuel treatment (such as envisaged under GNEP[1]) has the potential to make current solvent-based reprocessing technology obsolete. If viability of the new technologies is proven there should be no requirement to build new plutonium separation plants (though there will be an ongoing need to counter the possibility of clandestine plutonium extraction plants). However, there

1. Global Nuclear Energy Partnership.

will be a continuing need for enrichment for the rest of this century, and an increase in global enrichment capacity will be needed from as early as the next decade.

From the outset of the nuclear era, it was envisaged that the nuclear-weapon states (NWS) would provide fuel cycle services for the non-nuclear-weapon states (NNWS), and this is how the nuclear industry has developed in practice. US, Russian, French and UK entities are the leading suppliers of fuel cycle services, on a commercial basis, to the world's civil nuclear industry – though two NNWS, Germany and Netherlands, are also major international suppliers of enrichment services.

The NPT, concluded in 1968, makes no explicit reference to SNT. Indeed, until the 1990s it was assumed that development of enrichment capability would be beyond the technological means of most states, so there was no need for detailed coverage in the Treaty. The NPT speaks of the "inalienable right … to … use of **nuclear energy** for peaceful purposes" (Article IV). The key points here are: the NPT refers to "nuclear energy", not particular technologies; and this right is not unqualified, but is subject to the other provisions of the Treaty – especially the commitments of NNWS not to seek nuclear weapons and to place all nuclear material under IAEA safeguards.

In light of recent developments – including the discovery of an extensive black market in enrichment technology and, closely related, Iran's pursuit of a uranium enrichment program – the need to limit the spread of enrichment capability is assuming increasing urgency. As will be discussed, this presents both technical and political challenges.

## 2. THE SPREAD OF ENRICHMENT CAPABILITY - SCOPING THE PROBLEM

Before considering the dimensions of the enrichment problem, it is worth looking at which states currently have enrichment capability. As well as the five NWS recognised by the NPT (US, Russia, UK, France and China), there are 10 other states with demonstrated enrichment capability – see Table 1 below.

**Table 1: States with demonstrated enrichment capability, in addition to the 5 NWS**

| Country | Technology | Source | Status |
|---|---|---|---|
| Argentina | Diffusion | Indigenous | Pilot |
| Australia | Centrifuge;<br>Laser | Indigenous;<br>Indigenous | Pilot – dismantled;<br>R&D - transferred to US |
| Brazil | Centrifuge | Indigenous | Commercialising |
| Germany | Centrifuge | Indigenous | Commercial-scale |
| India | Centrifuge | Indigenous | Military, limited |
| Iran | Centrifuge | Illicit | Pilot |
| Japan | Centrifuge | Indigenous | Commercial-scale |
| Netherlands | Centrifuge | Indigenous | Commercial-scale |
| Pakistan | Centrifuge | Illicit | Military |
| South Africa | Aerodynamic | Indigenous | Dismantled |

In addition to these states, **Iraq** had developed electromagnetic separation and centrifuges, and **Libya** had acquired assembled centrifuges – these programs have been destroyed/removed – and the **DPRK** is believed to have an illicitly sourced centrifuge program.

From this Table, three observations can be made: enrichment capability is already widespread; in most cases this has been developed indigenously (but those programs of proliferation concern originated with illicitly-procured technology); and centrifuge is the predominant technology.

**Risks from the spread of enrichment**

The risks can be broadly outlined as follows:

- Break-out from non-proliferation commitments using declared (safeguarded) facilities;
- Break-out using clandestine facilities;
- Illicit transfer of enrichment technology to further states.

The following discussion is based on centrifuge technology. The points made however are also relevant to other enrichment technologies.

**Break-out using declared facilities**

To produce weapons-grade HEU (high enriched uranium) efficiently requires centrifuges and cascades optimised for the task. However, inefficiency can be compensated by high throughput (i.e. large-scale plant). A centrifuge enrichment plant designed for LEU (low enriched uranium) could be used to produce HEU with only limited changes to the plant (some changes to pipe work) and operating parameters (gas pressures and flow-rates).

Break-out potential can be illustrated with the following figures.

- A smallish commercial-scale plant - 1 million SWU - processes around 2,000 tonnes U (2,900 tonnes $UF_6$) a year, to produce 230 tonnes LEU (as U, or around 340 tonnes $UF_6$) at 3.5% enrichment, and 0.30% tails assay. Daily output is around 630 kg LEU.

- If this plant were diverted to military use, and continued to use natural uranium (NU) feed, theoretically it would be capable of producing 5,180 kg of HEU at 90% enrichment in one year – around 14 kg/day. In other words, the plant could take just **2 days** to produce a safeguards *significant quantity* (1 SQ - 25 kg U-235).[2]

- The most effective break-out scenario is to use LEU feed – to keep some LEU product on hand[3], and use that when the break-out decision is taken. In this case, using 3.5% enriched LEU, theoretically 1 SQ of HEU at 90% enrichment could be produced in around **18 hours**.

The following comments should be made:

- These figures represent a theoretical worst case – in practice throughput will be less due to necessary changes in operating parameters, precautions against criticality, etc. More realistic figures might be, respectively, production of 1 SQ HEU from NU in the order of **10-12 days**, or

2. Assuming the same tails assay as the first example, 0.30%. The SQ is a standard unit for purposes of safeguards analysis, and is used in this paper, though the quantity required for a basic implosion weapon is more like 15 kg U-235.
3. Stockpiling of LEU cannot be taken as an indicator of intended misuse, as in the ordinary operation of an enrichment plant there would always be significant quantities on hand. A standard 30B product cylinder contains 1400 kg U, representing just over two days output for the first example above. It would be normal practice to have several such cylinders on hand. The contents of each would be sufficient to produce around 1.5 SQ of HEU.

from LEU in the order of **3-4 days** – though shorter times, closer to the theoretical figures, cannot be excluded.

- It is doubtful that safeguards inspections would be capable of proving **timely warning** in the scenarios discussed here – misuse could easily occur between inspections. Remote monitoring could provide warning as facility misuse occurs – but would this be **timely** (i.e. in sufficient time to enable international intervention before SQs had been produced and concealed/weaponised)?
- A smaller plant would have longer lead-times, e.g. for a 100,000 SWU plant[4] the indicative timings shown above might be extended to say 4-5 weeks for producing 1 SQ of HEU from LEU feed. Nonetheless, timely detection would be a challenge for safeguards – in principle the time to produce 1 SQ of HEU could be as little as 8 days.

The very short break-out times possible indicate that **safeguards measures alone are not sufficient to address concerns about enrichment capability**. Safeguards need to be reinforced by other measures – one essential measure being to limit the states with these facilities.

**Break-out using clandestine facilities**

Centrifuge plants have a small "footprint" (compact size, low power requirements, low thermal output), making detection difficult. A clandestine plant can be optimised for HEU. To produce 1 SQ of HEU in a year from a dedicated plant requires a little over 5,000 SWU, i.e. some 2,000 fairly basic centrifuges[5]. Detection of such plants presents a major challenge both for the IAEA and for national intelligence agencies.

The time and/or scale needed to produce HEU at a clandestine plant can be substantially reduced by use of LEU feed. While it can be expected that significant diversion of LEU from a safeguarded facility will be detected, whether detection will be sufficiently timely for effective intervention would depend on the scale of the clandestine plant and whether this plant can be located.

**Illicit transfer of technology**

Maintaining effective control over sensitive technology is always a challenge. This requires great care in security clearances of individuals, procedures for storage of and access to sensitive information, etc. The more people have access to such information, the greater the risk of unauthorised disclosure. The risk increases with the spread of sensitive information to more states, where rigorous protection cannot be assumed (indeed, the possibility of *authorised* transfer of sensitive information to additional states, or even non-state actors, cannot be excluded).

**Proliferation resistant enrichment technology**

There is some debate whether certain enrichment technologies are inherently proliferation resistant. An example is the French Chemex process, which for criticality reasons cannot be used for high enrichment. A current example is the Argentinean SIGMA diffusion process, for which it seems misuse of a declared plant to produce HEU would be impracticable. However, even if a process is proliferation resistant, it could be used to contribute enriched feed to a clandestine program (if necessary based on another technology), so even a "proliferation resistant" enrichment technology will not be free of proliferation concern.

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4. 100,000 SWU is around the estimated capacity of Iran's Natanz facility when completed.
5. Such a plant might occupy less than 1,000 $m^2$ and draw less than 100kW.

## 3. MEASURES AGAINST THE SPREAD OF ENRICHMENT CAPABILITY

To date these have been focused primarily on **denial** – application of export controls to limit the transfer of enrichment technology, including equipment, components and special materials. Export controls are applied nationally, but largely reflect understandings reached multilaterally, through the NSG (Nuclear Suppliers Group). The NSG has formulated two sets of Guidelines: Guidelines for Nuclear Transfers (published as IAEA document INFCIRC/254, Part1), covering the export of items that are especially designed or prepared for nuclear use; and Guidelines for Transfers of Nuclear-Related Dual-Use Equipment, Materials, Software and Related Technology (INFCIRC/254, Part 2).

Also important is Security Council Resolution 1540 of 2004, which requires **all** states to implement effective export controls and other measures to prevent the spread of weapons of mass destruction.

While export controls, including through application of the NSG Guidelines, are an essential part of international action to limit the spread of enrichment technology, they are not sufficient in themselves. As Table 1 shows, a number of states have pursued enrichment projects based on technology that is indigenously developed or illicitly procured. Export controls can impede such projects where some imported components or materials are required, but are not effective against wholly indigenous projects.

More recently there have been initiatives to establish a **political framework** in which decisions on transfers of SNT would be taken. At one end of the spectrum is the proposal made by President Bush in 2004[6] that NSG members should refuse to transfer enrichment (and reprocessing) equipment and technology to **any** state not already having “full-scale functioning” facilities[7].

An alternative, endorsed by the G8[8], is the **criteria** approach – for SNT to be exported “only pursuant to criteria consistent with global non-proliferation norms and to those states rigorously committed to these norms”[9]. The NSG is developing such criteria – the G8 has welcomed the progress made. Details of the NSG’s deliberations are not publicly available, but possible criteria might include:

- the state’s non-proliferation and safeguards record, including whether it has a safeguards Additional Protocol in place;
- whether there is a clear rationale for the proposal in terms of energy requirements and economics;
- whether the proposal is wholly national or involves others, e.g. through multination/regional arrangements;
- whether the proposal has any implications for international/regional security and stability.

Recent initiatives have shifted focus from supply and denial policies to addressing **demand** – how to create conditions under which states which might otherwise consider national enrichment projects would have no reason to continue – indeed would have **incentives** not to do so. For example, a number of proposals involve **supply assurances** – that states choosing to forgo national enrichment projects would be given assurances about the supply of nuclear fuel at commercial prices.

The most comprehensive such proposal is **GNEP**, under which “fuel users” could receive the benefit of assured supply of reactor fuel from fuel suppliers without having to make the major infrastructure investments required for enrichment, recycling and disposal facilities. Fuel users could avail

6. Address to National Defense University, 11 February 2004.
7. Understood to mean, as at the end of 2003.
8. The Group of Eight, comprising Canada, France, Germany, Italy, Japan, Russia, UK and US.
9. G8 Summit Statement on Non-Proliferation, St Petersburg Summit, 16 July 2006.

themselves of “cradle-to-grave” fuel management, including spent fuel take-back – this, and avoidance of the substantial capital (and possibly political) costs of pursuing enrichment, would provide a powerful incentive for most states not to seek their own enrichment capability.

Mention should also be made of the concept of **international fuel supply centres**. This concept was advanced in the 1980 INFCE[10] report – the idea was that SNT projects should not be solely national projects but should be operated by multination groups. The involvement of several states would help ensure sensitive facilities were not misused. Russia has advanced another version of the concept – an international centre involving enrichment and related services is to be established in Russia, under IAEA monitoring. Interested states could join, securing a share of product and economic benefits, but without having access to the technology[11]. Further development of this concept was endorsed by the G8 2006 St Petersburg Summit.

## 4. ASSESSING THE PROLIFERATION RISK OF ENRICHMENT PROJECTS

In considering how to assess the possible proliferation risk presented by new enrichment projects, it is necessary to consider the nature of the risk. As discussed above, from a purely **technical** perspective, possession of an industrial-scale centrifuge plant could present a significant proliferation risk. It is simplistic, however, to maintain that the risk is the same in all circumstances. In assessing the **practical** risk, key factors include:

- What is the actual enrichment capability of the state?
- Are there relevant institutional arrangements for the project?
- Relevant state-specific factors.

### Actual enrichment capability

Where the proposed project involves transfer of equipment/technology, it is important to look at exactly what would be transferred. If the state will manufacture and assemble sensitive components, conduct a significant enrichment R&D program, etc, then the consequence is that the state would acquire the capability to develop a clandestine program, using the declared program as cover (e.g. for manufacturing centrifuges, R&D, training personnel, etc). Such a situation is qualitatively different to the case where the state would receive an enrichment facility on a “**black box**” basis, i.e. the technology supplier provides, installs, operates and maintains assembled centrifuges. This is the approach of the Urenco group – Urenco is supplying centrifuges to French and US facilities on this basis. Effectively there is **no transfer** of enrichment technology to the host state.

### Institutional arrangements

Broadly speaking, the greater the international involvement in an enrichment project, the more constraints there will be on misusing the facility. For a wholly national project, the only constraint may be the risk of detection by safeguards. If the facility includes foreign personnel, this would complicate any scheme to misuse the facility (depending on how closely the foreign personnel were involved in operations – and of course absent collusion!). The strongest counter to misuse would be where the facility is operated by the technology supplier rather than the host state – this would result in immediate warning if the host state seized the facility, plus some delay while host state personnel sought to familiarise themselves with the operation of the facility.

10. International Nuclear Fuel Cycle Evaluation.
11. President Putin, address to Eurasian Economic Community, St Petersburg, 25 January 2006.

Bilateral or multination involvement has a further advantage – not only would there be immediate warning of misuse, but the host state would have to contend with the objections of the other states involved as well as the IAEA. This is a further inhibiting factor – a state aggrieved by breach of project agreement may have a number of options for practical intervention.

**State-specific factors**

There is reluctance on the part of some to consider state-specific factors, in case this implies a discriminatory process. Nonetheless, it is a fact that there **are** marked differences between the non-proliferation performance of various states. From the perspective of states with strong non-proliferation credentials, it is discriminatory **not** to take this into account.

What assessment of a state can be made in proliferation terms – non-proliferation commitment, factors impacting on motivation, existence of proliferation indicators, etc? Such assessment could involve a wide range of factors, including: the strategic environment of the state; whether the state has met all safeguards requirements, is cooperating fully with the IAEA, and is implementing an Additional Protocol; whether the stated rationale for the enrichment project is consistent with the state's energy or commercial circumstances; whether there are any indicators of an interest in proliferation, and so on. Some argue that matters of this kind involve subjective judgments. Closer reflection will show that there are observable facts and indicators associated with most of these factors – and these are capable of objective identification and analysis[12].

5. CONCLUSIONS

It is self-evident that an enrichment project should not proceed in a situation where it will generate major strategic concern. Of course, the opposite does not necessarily follow. The fact that a state gains a positive assessment today does not mean it might not pose a proliferation risk in the future – governments change, as do strategic circumstances. Accordingly, a cautious approach is called for.

What, then, should this approach be? An approach of blanket denial – no technology transfers to states not already operating large-scale facilities – may be appropriate as an interim position, as ideas are developed further, but is not a satisfactory basis for a definitive regime: there seems no reason in-principle why new or expanded projects by existing NNWS enrichment states should be exempt from scrutiny on non-proliferation grounds, and there is the question of how to deal with projects that do not involve overt transfers (discussed below).

As a concept, the "criteria" approach, endorsed by the G8 and under development in the NSG, offers a more comprehensive approach. Some are concerned however that any criteria capable of gaining general support will be too broad, and could result in too many states qualifying. Is this necessarily the case?

In practice the number of states that might consider enrichment, at least for legitimate commercial projects, is likely to remain fairly small. Establishing enrichment involves very high costs, for most states it would not be economic. Pursuit of enrichment would be even harder to justify if a global framework for nuclear development is established that addresses supply assurance issues.

Much of the concern here is generated by the Iranian situation – the strident assertion of the "right" to an enrichment program, and Iran's success in persuading others to support this "right", notwithstanding its breach of the NPT from which this "right" is derived, and its history of safeguards

12. For further discussion of these issues see *Assessing Motivation as a Means of Determining the Risk of Proliferation*, A.Berriman, R.Leslie and J.Carlson, INMM 2004 Annual Meeting.

non-compliance. Iran should not be viewed as a "typical" case of a state interested in enrichment – and indeed the Iranian program did not involve an overt transfer of technology, as would be addressed by the proposed NSG criteria, but a clandestine program based on illicit procurement.

The Iranian situation highlights an important point – that **a process needs to be established to assess the international acceptability of enrichment projects regardless of their origin**, whether they are based on transfers, illicit procurement or indigenous development. This is in effect what is happening now with Iran – the basis of Security Council action is Iran's safeguards violations and defiance of the IAEA Board of Governors. Underlying this is concern about the potential threat the Iranian enrichment program poses to international peace and security. The international community needs to learn from this experience, and develop a generic framework for addressing SNT projects.

The Iranian case illustrates a number of factors that would be relevant to an assessment process (whether "criteria" or some other term is used to describe the process). Some of the key factors that might be considered are outlined as follows:

- **Non-proliferation record –** absence of major safeguards problems, full cooperation with the IAEA, implementation of the Additional Protocol, would all be regarded as positive factors. Obviously the converse would be regarded as negative factors. Given the potential for very short break-out times (discussed earlier), the state should be willing to accept stronger and more intrusive safeguards and transparency/confidence-building measures.
- **Technological capability –** if the state were manufacturing sensitive components, conducting SNT R&D, etc, this might, depending on the assessment of the other factors discussed here, be regarded as a negative factor, or at least indicate the need for stronger safeguards/transparency measures. In principle, "black box" arrangements would be a positive factor.
- **Institutional arrangements** – technology holder or multination involvement should be a positive factor. However, structuring a project on a multination basis would fail to provide confidence if there was a concern about possible collusion or seizure by the host state.
- **Project rationale –** clearly an unconvincing rationale would be a negative factor.
- **Strategic environment** – an essential consideration is the potential for the project to be misused in the future, as well as the impact of the project on the security perceptions of other states.
- **Non-proliferation benefit –** an example would be a multination project involving states that might otherwise consider pursuing individual national enrichment programs.

This discussion should demonstrate the complexities of establishing an international framework for controlling the spread of enrichment capability. Complexity however does not mean such a framework should not be pursued, or is unattainable. A policy of blanket denial does not effectively address all issues, and is unlikely to gain international acceptance. A more comprehensive approach is called for, meeting the concerns of states for assured fuel supply at competitive prices, while avoiding increased proliferation risk. Such an approach should not exclude the possibility of some limited addition to the states undertaking commercial enrichment, provided proliferation aspects are fully addressed. Developing and implementing a satisfactory approach will be a challenge, but can be achieved through the right mix of diplomacy and incentives.