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Nuclear Power, Disarmament and Technological Restraint

James M. Acton

After years outside the political mainstream, the goal of abolishing nuclear weapons is once again receiving significant attention. There is a growing consensus that if key non-nuclear-weapons states are to be persuaded to strengthen the non-proliferation regime, nuclear-weapons states must start to live up to their commitment – enshrined in Article VI of the Nuclear Non-Proliferation Treaty (NPT) and reaffirmed when the treaty was indefinitely extended in 1995[1] – to work in good faith towards the elimination of such weapons.[2] The clearest example yet of abolition's newfound respectability came on 5 April 2009 when President Barack Obama laid out 'America's commitment to seek the peace and security of a world without nuclear weapons' and outlined some practical steps towards that goal.[3]

Almost in parallel with the resurrection of disarmament as a mainstream policy, nuclear power has undergone something of a rebirth. It is increasingly seen as part of the solution for global warming, and many states have recently announced new or revived nuclear-power programmes.[4] Yet nuclear power carries with it the risk of proliferation. If the anticipated nuclear-power renaissance does indeed result in the further spread of nuclear weapons, disarmament will inevitably become more distant and difficult.

Squaring nuclear power with nuclear disarmament will require a multi-faceted approach.[5] International Atomic Energy Agency (IAEA) safeguards will need to be improved to enable the more effective verification of peace-

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ful nuclear activities. The political barriers to proliferation will also need to be strengthened by ensuring that the UN Security Council acts upon incidences of non-compliance much more quickly and robustly than it does today. Further measures could include placing all sensitive nuclear activities under multinational control and constructing the nuclear industry around less proliferation-sensitive technologies, the concept addressed in this article.

The most sensitive steps in the nuclear fuel cycle are uranium enrichment and reprocessing,[6] which can be used to make weapons-usable material directly, as well as ingredients for reactor fuel. Nuclear reactors pose a smaller proliferation risk, but the risk is not zero because of the danger that a state might secretly extract plutonium from spent fuel. The most sensitive reactors are heavy-water reactors[7] and fast reactors[8] because they are harder to safeguard and generally produce plutonium that is particularly suitable for nuclear weapons.[9]

Unfortunately, non-proliferation strategies frequently conflict with other goals, particularly economic ones. For instance, the cheapest enrichment technology currently available is the gas centrifuge. The few remaining plants that use an older technology (gaseous diffusion) are now scheduled to be shut down. However, the fact that small gas-centrifuge plants are very efficient and hard to detect have made them de rigueur for proliferation-oriented states in recent years. Iran, Libya and Pakistan all based their weapons programmes on the gas centrifuge, and it was the most promising element of Iraq's nuclear programme prior to its termination in 1991.

Policymakers, industry insiders and regulators have usually failed to factor proliferation concerns into decisions about nuclear energy. If the policy of abolishing nuclear weapons is to be anything more than rhetoric, proliferation concerns will have to be taken much more seriously and given due weight in decisions about nuclear energy. In some cases, this might involve the decision to forsake a technology that offers an economic advantage where this is outweighed by the proliferation risk.[10] Realistically, the gas centrifuge is too economically advantageous, and its use too entrenched, to be phased out. The opportunity does exist, however, to forsake enrichment and other nuclear technologies that have not yet been commercialised.

Today, for instance, Global Laser Enrichment (GLE, owned by General Electric Hitachi) is attempting to commercialise a new enrichment process (known as the SILEX process) based on lasers.[11] GLE expects that the SILEX process will be more profitable to enrichment firms than other technologies. However, the economic benefits of cheaper enrichment to electricity consumers are slight because enrichment typically accounts for less than 5% of the total cost of nuclear electricity.[12] Meanwhile, laser enrichment is probably even more worrying from a proliferation perspective than the gas centrifuge because detecting a small, clandestine laser-enrichment plant is likely to be even harder than detecting a secret gas-centrifuge enrichment plant of a similar capacity.[13] Regulators should factor such concerns into licensing decisions for all nuclear technologies and be willing to deny applications if they determine that the costs outweigh the benefits, as is almost certainly the case with GLE, for instance. Forsaking sensitive nuclear technologies on non-proliferation grounds would be controversial, but justifiable.

Justifying technological restraint

In economic theory, proliferation (along with the risk of accidents and problems associated with the disposal of nuclear waste) is a 'negative externality' of nuclear power: that is, a cost incurred by parties other than those directly involved in a transaction.[14] The existence of negative externalities is a key reason why the market, left purely to its own devices, may not produce the best outcomes. It is one reason why governments must sometimes intervene in markets. Although governments have hardly been shy of intervening in energy policy, they have had a strong tendency to simply ignore the externalities of nuclear power (along with those of every other form of power generation, for that matter), as the failure of almost every state with nuclear power reactors to plan for long-term waste storage demonstrates.[15] Yet externalities represent real costs and ought to be fully 'internalised' in any decision about nuclear energy. As the world moves towards abolition and becomes more sensitive to proliferation, these costs will effectively increase.

A number of authors, including Henry Sokolski, have argued that the economic costs of proliferation, such as the financial burden of maintaining IAEA safeguards, ought to be internalised.[16] But the financial costs that could conceivably be apportioned in this way represent just a small fraction of the total 'proliferation cost'. Some of this cost – such as the more aggressive foreign policy a state that feels protected by nuclear weapons may be inclined to pursue – is non-economic in nature, but no less real. Others costs, such as the effect on oil prices of proliferation crises centred on key oil-producing states, are economic but effectively unquantifiable.

Nuclear-energy policy, like energy policy more broadly, necessarily involves weighing up incommensurable variables. This task can neither be avoided nor regarded as a purely economic decision to be delegated to the capital market. The challenge of factoring in all the costs – internal and external, economic and uneconomic – necessarily falls upon politicians and regulators. Political judgement, not mathematical calculation, is ultimately required. Formulating energy policy without considering all the costs (quantifiable or not), deciding upon their relative importance and weighing them up is a dereliction of duty.

Political judgement, not mathematical calculation, is required

The suggestion that governments should make nuclear-energy decisions on the basis of uncertain and non-economic costs may be anathema to some, but all governments have to act on this basis sometimes. An excellent example is the ongoing efforts to reduce carbon emissions in order to combat climate change. Emissions that lead to climate change are an externality of power generation, in particular the burning of fossil fuels. The development of a cap-and-trade system is an effort to force the market to internalise this cost by penalising entities that are unable to reduce their emissions. In theory, the price of permits within a cap-and-trade system should be set at the marginal cost of emitting one tonne of carbon, the so-called social cost of carbon (SSC). However, governments have – quite rightly – started to enact cap-and-trade systems even though estimates for the SSC are highly variable, spanning two or three orders of magnitude.[17] Moreover, the Intergovernmental Panel for Climate Change points out that figures for the SSC almost certainly 'underestimate the damage costs because they cannot include many non-quantifiable impacts'.[18] Nevertheless, these non-quantifiable costs, such as the social, health and environmental impacts of climate change, dominate the public discourse and have been key in prompting governments to take the issue seriously.

Develop and deny?

The nuclear industry generally defends the deployment of sensitive technologies by arguing that it is more-or-less possible to eliminate any proliferation cost by adopting a strategy of 'develop and deny', that is, by not sharing sensitive technologies at all, or by sharing them with only a few 'safe' states. The former variant was enshrined in US law by the McMahon Act of 1946, in force until the 1954 Atomic Energy Act permitted the sharing of nuclear technologies with other states. The latter variant was the approach taken by the George W. Bush administration.[19] By simultaneously calling for the development of 'proliferation-resistant' technology, however, the Bush administration effectively acknowledged the limitations of a strategy of develop and deny. After all, if technology really could be restricted to 'safe' states, why would it need to be proliferation-resistant?

To understand why domestic decisions about nuclear energy cannot be decoupled from proliferation concerns, it is necessary to recognise that nuclear-power decisions are often taken on grounds other than detailed analyses demonstrating that the chosen option is the cheapest available, or that it provides longer-term economic benefits such as energy security. In particular, prestige and 'received wisdom' – the assumed belief, often based on the actions of other states, that a given nuclear technology is too lucrative to be missed – have been very important, both in driving states to start nuclear programmes and in influencing their technological choices. The provision of a nuclear-weapons hedging option is also important.

That nuclear technology is a potential source of prestige is widely recognised.[20] For instance, Brazil's centrifuge programme, with its aim of producing enriched uranium for the country's power reactors, in spite of a significant cost penalty, is now driven in large part by the prestige associated with enrichment.[21] The importance of received wisdom, on the other hand, is perhaps underappreciated. Received wisdom, especially from the United States, has been crucial in shaping the development of nuclear power. It explains the plans developed prior to the mid 1970s by every state with a nuclear power-programme outside the Soviet bloc (apart from Canada) to develop 'closed' fuel cycles, that is, to reprocess spent fuel and use the extracted plutonium as reactor fuel.[22] Indeed, when the United States changed its policy and opposed reprocessing in 1976, Japanese diplomats were apparently fond of remarking that 'our belief in the necessity of the plutonium cycle is based on American teaching'.[23]

There is no evidence that interest in the closed fuel cycle in these states was based on detailed economic analyses. Certainly, the evidence strongly suggests that the two Western states with the most-developed nuclear-power programmes prior to the 1970s, the United Kingdom and United States, simply assumed that the economics of reprocessing were favourable.[24] Indeed, as late as 1978, the report of the inquiry into the planning application by British Nuclear Fuels Limited (BNFL) to build the THORP reprocessing facility observed that 'although BNFL made alleged financial advantages part of their case, no detailed financial analysis was produced by them'.[25]

Given the roles that prestige and received wisdom play in procurement, decisions by advanced nuclear states to develop or deploy nuclear technologies can make it more likely that other states will try to follow suit. This effect can be exacerbated by the way a discriminatory approach can actually enhance the prestige associated with nuclear technologies.[26] An example is provided by South Korea, which is interested in developing a new reprocessing technology called Advanced Fuel Conditioning, but more usually referred to as pyroprocessing.[27] Because of the country's use of US-origin technology and fuel, South Korea requires US consent before it can reprocess any fuel. This permission has so far been withheld, although it was given to South Korea's neighbour and historic adversary, Japan, which now has a long-standing reprocessing programme.

Officially, interest in pyroprocessing is motivated by a desire to promote energy independence and reduce waste volumes. But as those involved in its development recognise, the benefits are not as significant as widely believed in South Korea.[28] In reality, at least part of the impetus behind pyroprocessing is the desire on the part of its advocates for equality between Japan and

South Korea. South Korea partly justified its interest in reprocessing in the 1970s with reference to the existence of a Japanese programme.[29] Today, many government scientists feel a deep sense of resentment that Japan is permitted to reprocess while South Korea is not.[30] Significantly, these are the same individuals who advise the government on fuel-cycle decisions. Given that government officials in any state rarely have a detailed understanding of nuclear technology, technical advisers can often wield considerable influence.

Of course, if denial really was effective at preventing the spread of a technology, these effects would not matter. In practice, preventing the spread of a technology is also extremely difficult, especially over the long timescales relevant to the problem of proliferation.

One risk is the illicit dissemination of classified or proprietary information, through the transfer of documents or the purchase of trained personnel, a concern that is perhaps most acute for Global Laser Enrichment. In this regard, the spread of the centrifuge is instructive. The UK–German–Dutch enrichment consortium URENCO has been the technological origin for the majority of proliferation attempts in recent years.[31] Most notoriously, A.Q. Khan, working for a URENCO contractor in the late 1970s, stole information that he subsequently used in developing Pakistan's centrifuge programme.[32] He then sold the technology to Iran, Libya and North Korea, and offered it to Iraq and possibly others as well. Independently, German contractors working for URENCO in the late 1980s and early 1990s sold sensitive information to Iraq and probably Brazil (although this is not certain).[33] The small Indian centrifuge programme almost certainly also received assistance from abroad, although its origins are unclear.

Preventing the spread of a technology is extremely difficult

Global Laser Enrichment argues that it can avoid similar occurrences with laser enrichment by classifying information.[34] Indeed, there is no question that security can be much tighter than it was in URENCO before the 1990s (and, to be fair, URENCO has taken the issue much more seriously since then). Equally, it is also true that, over the course of many decades, the commercialisation of laser enrichment in the United States, which necessarily involves many scientists having access to sensitive information, significantly increases the risks of the technology diffusing, not least because it may become the target of industrial espionage conducted by foreign governments as well as other companies.

Beyond the illicit dissemination of technology, there is also the possibility of indigenous development, aided by information that is legitimately in the public domain. Even if much additional research is inevitably needed to put theoretical concepts into practice, open-source literature can give a state a significant head start in attempting to develop any nuclear technology, as declassified designs for the British Calder Hall reactor did for North Korea,[35] or its Atoms for Peace Library did for Iraq.[36]

The problem of indigenous development is undoubtedly most acute for reprocessing. Extensive information on the PUREX process (developed by the United States to produce plutonium for the *Manhattan Project*) is in the public domain, meaning the most important barriers to its development are political rather than technical. Given that a strategy of develop and deny lowers the political barriers, it is unrealistic to expect that, over the long term, this kind of discriminatory approach can be effective.

The problems of develop and deny would remain even if, as proponents of reprocessing have recently advocated, advanced nuclear states switched from PUREX to newer technologies that do not involve the separation of pure plutonium. Even apart from the over-selling of their claimed non-proliferation benefits,[37] the adoption of these technologies would still send the message that the recycling of spent fuel has an important role to play in the development of nuclear energy. Because PUREX is the simplest process, it is the one to which other states are most likely to turn, especially if they are also seeking a nuclear-weapons hedging option. Indeed, a state wishing to develop PUREX could make its case even stronger, at least in the eyes of many developing states, by first asking for help with the development of advanced reprocessing, with the knowledge that the request would be refused.[38]

Countering the inevitability argument

Achieving agreement among all states on the need to forsake particular technologies where the non-proliferation costs are sufficiently high presents a tremendous challenge. In the short term, the idea of new binding rules on access to nuclear technologies is a non-starter, although at least some of that resistance is directed against a discriminatory approach.[39]

Absent global agreement, the nuclear industry in states deciding to forsake technologies unilaterally is likely to make the argument that 'if we don't develop it, someone else will'. Indeed, this was a key argument of the US nuclear industry against President Jimmy Carter's decision to desist from domestic reprocessing.[40]

Policymakers and regulators certainly ought to weigh this concern in deciding whether to fund or license novel technologies. However, the technological trajectory of nuclear energy is not inevitable. Decisions by key states not to fund research and development into novel technologies can result in them not being commercialised.

Moreover, states that are serious about disarmament, and have chosen to forsake certain technologies on non-proliferation grounds, can take steps to shape the technological trajectories of others, making it less likely that they will seek the same technologies. These steps include stopping domestic use of the most sensitive technologies, trading in less sensitive technologies, and taking back spent nuclear fuel. These options are useful first steps on the way to a legally binding instrument banning the most sensitive technologies.

History shows the flaws in the nuclear industry's argument that the technological trajectory of nuclear energy is inevitable and that it is therefore pointless for individual governments to forsake sensitive technologies. Looking back, for instance, it is clear that there was nothing inevitable about the success that the light-water reactor (LWR) enjoys today. As of 2008, LWRs accounted for 359 out of 441 reactor units in operation and almost 90% of their total electrical output.[41] This dominance was the result of a conscious, deliberate development strategy. During the early days of commercial nuclear power, two other designs, the gas-cooled reactor (GCR) and the heavy-water reactor (HWR), were competitive; indeed, the GCR was the market leader until the mid 1960s.[42] Given that the GCR and HWR are simpler and do not use enriched fuel, the dominance of the LWR was far from inevitable. Indeed, the debate about the light-water reactor's technological superiority is still not settled, including among those with no financial stake in HWR sales.

The success of the LWR resulted from significant investment by the United States and Russia. Almost every such reactor operating today has its origins in US or Soviet technology. Although other nations do manufacture LWRs – indeed, there are now no wholly US-owned suppliers – the non-Russian designs all originated from technical transfers from the United States.[43] The only partial exceptions are nine Swedish-origin and four Chinese-origin reactors that are largely, but not completely, indigenous.[44] US interest in the LWR stemmed from a programme to develop reactors for naval propulsion. The two key US nuclear engineering firms, Westinghouse and General Electric, were deeply involved in this programme. Had Washington not had an interest in the LWR as a naval-propulsion reactor and not been willing to further develop it for civilian use, the GCR and HWR may well have ended up as the industry standard today. (Given that the LWR is less proliferation sensitive than either the GCR or HWR, its success was a considerable non-proliferation good.)

The argument against inevitability only becomes stronger in the case of more sophisticated technologies requiring much larger capital costs, such as the fast reactor or laser enrichment. Decisions by a few key states – or perhaps the United States alone – not to invest in these technologies and instead to focus on alternatives (whether renewables or other types of nuclear technology) increase the likelihood that some technologies will not be developed at all.

Fast reactors, for instance, have been under development since the early days of nuclear power; the first nuclear reactor ever connected to an electric grid was a fast reactor. However, as research has progressed and the technical challenges of this technology have become more apparent, the prospect of commercialised fast reactors has remained distant, and their costs have continually increased. The United States alone spent $25bn (in 2009 dollars) on fast-reactor development prior to the development programme's cancellation in 1988, and failed even to start building a prototype commercial reactor.[45] Prior to the Bush administration's renewed advocacy of the concept, all states except Russia were losing interest.[46] It is far from clear that interest in fast reactors will survive the combination of the Obama administration's much more sceptical attitude[47] and the current financial crisis.

Desist and discourage

Where states believe that the proliferation costs of an activity outweigh its benefits, they can cease to conduct that activity themselves and adopt a strategy of 'desist and discourage'. This strategy aims to remove a potential stimulus for other states to start a proliferation-sensitive activity, such as reprocessing. The classic example is the US moratorium on civilian reprocessing, which was announced (albeit somewhat equivocally) in 1976 by President Gerald Ford and restated (in more unambiguous terms) by Carter and Bill Clinton.[48] Although neither of the Republican presidents between Carter and Clinton (Ronald Reagan and George H.W. Bush) opposed reprocessing in principle, they did very little, in practical terms, to support it.[49]

The appropriate way to evaluate a strategy of desist and discourage is to ask whether it not only discourages states from taking small-scale research programmes to an industrial level, but leads states to avoid launching new reprocessing programmes in the first place. (Small-scale reprocessing programmes are perhaps even more worrying from a proliferation perspective than their industrial-scale counterparts.) For this reason, the claim from a recent Department of Energy report that 'U.S. opposition [to reprocessing] has not slowed large-scale reprocessing programs in Europe, Japan, and Russia',[50] while true,[51] is also somewhat beside the point. What the Department of Energy's statement really underlines is that, because of the web of political, legal and financial commitments needed to create such multibillion-dollar programmes, it is extremely difficult to stop them once they have been set in motion. This phenomenon, termed 'entrapment' by William Walker,[52] highlights the importance of a policy aimed at stopping such programmes before they have even started. Here, there is evidence that the US moratorium had a positive, albeit modest, effect.

Most Western nuclear-power programmes prior to the mid 1970s were built around the expectation that power-reactor fuel would be reprocessed. The seminal 1976 study *Moving Towards Life in a Nuclear Armed Crowd?* observed that, given contemporary plans, 17 states would have reprocessing facilities and enough separated plutonium for between three and six nuclear weapons by 1985;[53] today, just eight or nine states (including North Korea) are reprocessing.[54] Not all of these stoppages were due to the US moratorium. Some programmes, such as South Korea's and Taiwan's (both of which had a clear military dimension), were avoided because of intense US pressure on both the supplier and recipient of reprocessing-technology transfers. Others, however, were influenced by the moratorium.

Today just eight or nine states are reprocessing

The US moratorium was one factor that led a number of states to stop treating reprocessing as an article of faith and to start assessing it on rational grounds; in other words, it helped destroy the received wisdom about reprocessing. Beyond the shock caused by an abrupt policy change, the US-sponsored International Nuclear Fuel Cycle Evaluation in 1977–79 also played a role. States developed and used a common methodology for assessing the economics of reprocessing.[55] This was probably the first time any of these countries (apart from the United States) had performed such an analysis. It did not end the debate on reprocessing – states essentially ended up arguing for their existing policies – but it did help start it. The United States also provided a model for other states as to how they could do without reprocessing.

The changes that the Italian nuclear industry underwent are typical. In Italy, the attitude toward reprocessing during the 1950s and 1960s could be summed up as 'why not?' Italy's nuclear programme was marked by the desire to keep all options open, including the possible development of nuclear weapons.[56] It experimented with multiple reactor designs and built two pilot reprocessing plants, Eurex and ITREC, that reprocessed a variety of fuel types.[57] As in many other states, reprocessing was strongly supported by the body responsible for nuclear research and development, the National Committee for Nuclear Energy (CNEN), later to become ENEA. CNEN perceived reprocessing as something that advanced nuclear nations just did.

Opposition to reprocessing in Italy came increasingly from Enel, the state-owned utility.[58] Although Enel publicly supported reprocessing, behind the scenes, high-level managers increasingly questioned its utility.[59]

ITREC and Eurex ceased reprocessing in 1980 and 1983, respectively. By the time of the Chernobyl accident in 1986 (which led Italy to abandon nuclear power completely), even CNEN was acknowledging that it made sense to defer reprocessing.[60] The evolution of policy in Italy was driven by a domestic debate about the economics of reprocessing and safety concerns about plutonium. From Italy's perspective, reprocessing no longer appeared in its interests, but that was very much the aim of US policy. By encouraging states to evaluate reprocessing on more rational, economic grounds, the moratorium had a positive, if modest, effect.

The moratorium had its limits, of course. It was fortuitous that during the late 1970s and early 1980s, concerns about energy security eased. Moreover, during the same period the nuclear industry entered a period of decline. (Italy, for instance, did continue to build nuclear reactors, but at a slower rate.) Local factors also played a role. In Italy, for example, the foreign and defence ministries, traditional supporters of reprocessing, gradually lost influence over nuclear policy after Italy's ratification of the NPT.[61] Nevertheless, the US moratorium did succeed in kick-starting a debate that showed little sign of being taken up otherwise.

There are some lessons to be drawn about implementing a strategy of desist and discourage that are relevant for current proliferation debates. Firstly, this strategy is most effective if the economics of the technology in question are not obviously favourable. (It is, therefore, more likely to be effective in relation to reprocessing than, say, laser enrichment, which potentially offers significant profits to the technology holder, even if the benefits to electricity consumers are modest.) Secondly, for a strategy of desist and discourage to be most effective, states need to do more than just abstain from certain nuclear technologies. Complementary means of discouraging others from acquiring these technologies, such as export controls, are also needed. Finally, one effect a strategy of desist and discourage may have that would be particularly relevant in the context of disarmament is to take some of the prestige out of nationally owned fuel-cycle facilities. In the event that all states cannot eventually agree to forsake a particular technology, its diminished prestige would help in reaching an agreement on placing remaining facilities under multinational control.

Develop and disseminate

The majority of states are reliant upon external suppliers for the provision of reactors. This presents an important opportunity to shape their nuclear-development paths through a strategy of 'develop and disseminate' for less sensitive technologies, such as light-water reactors.

The proliferation costs of *not* selling less-sensitive technologies are frequently underplayed. A dramatic example is the US decision to cut the United Kingdom and Canada out of the development of civil nuclear power after the Second World War. Reluctant to rely on the United States as a supplier of enrichment, Britain and Canada decided to focus on reactors that did not use enriched uranium (GCRs and HWRs, respectively). These reactors are, however, more suitable for proliferation than LWRs (which is not to say that LWRs are proliferation proof). Indeed, the Indian nuclear-weapons programme was based on a Canadian-supplied HWR. South Korea tried to acquire an almost identical reactor in the early 1970s, when it was pursuing a nuclear-weapons option.[62] And, as noted above, North Korea produced plutonium for its weapons programme using a GCR based on a British design.

The US plays a pivotal role in the global nuclear trade

Conversely, US cooperation with South Korea on reactor development has had more positive effects. South Korea initially had a mixed strategy of buying both Canadian-supplied HWRs and French- and US-supplied LWRs. In the 1980s, it focused solely on the LWR, developing its own variant of a Westinghouse design under license, in an effort to become independent.[63] A key reason for focusing on the LWR seems to have been that, from the South Korean perspective, the United States was the most attractive partner for cooperation, so South Korea ended up adopting the technology in use there. In other words, the choice of partner was at least as important as the choice of technology.[64]

The United States plays a pivotal role in the global nuclear trade. It is viewed as an attractive partner by its friends and allies, even though it insists on tougher non-proliferation conditions than its competitors. Currently, Washington is indicating a willingness to enter into cooperation agreements that could ultimately lead to reactor sales. Although these agreements have been criticised in some quarters, failing to negotiate them increases the risk that sales will be made by other vendors that impose less-stringent proliferation conditions (such as Russia) or can provide more proliferation-sensitive technologies (such as Canada). Moreover, if the United States is also contracted to supply fuel, it has the option to cut that supply if the recipient violates its non-proliferation obligations. If the US government were actually willing to use this option it would provide a powerful sanction against proliferation.[65]

None of this is to suggest that the United States (or any other vendor) should sell reactors to any state regardless of its non-proliferation credentials, or that if the United States competes for a contract it will always win. Rather, the lesson is that sales can present a potentially positive opportunity for non-proliferation and that this should be taken into account when deciding whether to sell.

Spent-fuel take back and waste management

'Take back' is the removal of spent nuclear fuel by the nation that supplied it, or even by a third party. From the perspective of states operating small nuclear-reactor fleets, take back is highly desirable because it eliminates the task of managing high-level waste and could, therefore, reduce the temptation to develop reprocessing as a way of delaying the politically challenging task of agreeing a long-term waste-management strategy. Moreover, many nuclear experts have recently argued that spent-fuel take back, coupled with a guaranteed supply of fresh fuel, might be the key inducement in encouraging states not to develop their own enrichment capability.[66] (In any case, few question its value as a non-proliferation tool.) Unfortunately, no state offers take back except Russia, for fuel that it supplied.[67]

The key area of dispute is whether reprocessing in the advanced nuclear states makes it easier for them to take back spent fuel. In December 2008, for instance, the US Department of Energy argued that, by simplifying the task of long-term waste storage, reprocessing 'would reduce technical barriers – and so could also reduce political barriers – to offering back-end fuel services'.[68] This comment referred specifically to a novel reprocessing technology that would separate out the highly radioactive components of nuclear waste that complicate its management, but similar arguments are made in favour of traditional reprocessing.

Even if the greater ease of storing reprocessed waste is taken as fact – and many opponents of reprocessing would not concede this point[69] – the problem with the Department of Energy's argument is that the barriers to long-term waste management are primarily political, as the statement essentially acknowledges. Just one illustration of these political barriers can be seen in the legislation that capped the capacity of the planned US geological storage repository at Yucca Mountain, a project now essentially abandoned, at between a quarter and a ninth of the quantity of waste that technical analyses demonstrated could be safely stored there.[70]

There are various objections to the take back of spent fuel. Among these is a visceral objection to turning any state into the 'world's nuclear dumping ground'.[71] It seems extremely unlikely that reprocessing in order to reduce the long-term waste-management challenges would convince those that have this objection of the merits of spent-fuel take back. Another, more subtle objection is that a state should not take back spent fuel from abroad until it has a satisfactory long-term plan for managing its own waste. Reprocessing advocates argue that by simplifying storage, reprocessing can help build a consensus around the geological-repository option. In practice, however, the controversy surrounding geological storage plans is likely to be increased by linking them to an even more controversial technology like reprocessing.[72]

Thus, not only does reprocessing clearly not help with facilitating take back, but if advanced nuclear states adopt it as a tool for waste management, it will be virtually impossible for them to argue against others doing likewise. Today, waste management is probably the most important driver for reprocessing. Indeed, the Bush administration's interest in this technology was born out of a desire to stretch the capacity of Yucca Mountain as far as possible. If the United States and others reprocess they will hand a powerful argument to lobbies within a state – typically the nuclear R&D community – that support the development of reprocessing.

* * *

The nuclear industry, as well as many policymakers and regulators, have often tried to decouple the challenges of non-proliferation from disarmament in order to avoid discussion of the limits that would have to be put on nuclear power to facilitate the abolition of nuclear weapons.[73] Nuclear energy is, however, an integral, if underappreciated, part of the disarmament challenge. If nuclear weapons and their entire supporting infrastructure were verifiably eliminated, the civilian nuclear industry would, by definition, provide the only route to rearmament. All states that profess to have an interest in nuclear disarmament, whether they possess nuclear weapons or not, therefore have an obligation to explore how to 'hardwire' non-proliferation into the nuclear industry. The failure even to consider the issue is, as Scott Sagan has argued, a refusal to live up to the commitment of pursuing disarmament in good faith.[74]

The possibility of a nuclear-energy renaissance has only increased the urgency of seriously considering the challenge. After all, if a significant expansion of nuclear energy occurs without being informed by the goal of abolishing nuclear weapons, it would make realising that goal much harder.

States and the nuclear industry should therefore start to explore disarmament practicalities. The first step in this process is for all those concerned with energy policy to do more than just pay lip service to the costs of proliferation and instead to internalise them in decisions about funding and licensing nuclear technologies, recognising that as nuclear arsenals are reduced, the costs of proliferation will rise. Fully factoring concerns about proliferation into nuclear-energy policy will necessarily promote a much-needed debate about whether some technologies are simply too proliferation sensitive to be deployed, in spite of potential economic benefits.

The long-term policy goal should be agreement on banning technologies deemed too dangerous. In the meantime, there is much that advanced nuclear states can do to steer others away from those technologies and pave the way for a ban. In particular, by desisting from the most sensitive technologies, trading in less sensitive technologies and facilitating the take back of spent nuclear fuel, even a small number of advanced nuclear states can shape the nuclear renaissance into a form that can help reconcile nuclear energy with nuclear disarmament.

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Notes

1 Article VI states that 'each of the Parties to the Treaty undertakes to pursue negotiations in good faith on effective measures relating to cessation of the nuclear arms race at an early date and to nuclear disarmament, and on a treaty on general and complete disarmament under strict and effective international control'. At the 1995 NPT Review and Extension Conference, the nuclear-weapons states reaffirmed 'their commitment, as stated in article VI, to pursue in good faith negotiations on effective measures relating to nuclear disarmament'. See 'Decision 2: Principles and Objectives for Nuclear Non-Proliferation and Disarmament', in *Final Document: Part I: Organization and Work of the Conference*, NPT/CONF.1995/32, Part I, Annex, 1995 Review and Extension Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons, New York, 1995, http://www.un.org/Depts/ddar/nptconf/2142.htm.

2 For an in-depth exploration of this argument see George Perkovich, *Principles for Reforming the Nuclear Order*, Proliferation Papers 22 (Paris: IFRI, 2008), http://www.ifri.org/files/Securite_defense/Perkovich_Reforming_Nuclear_Order.pdf; and William Walker, 'Nuclear Enlightenment and Counter-Enlightenment', *International Affairs*, vol. 83, no. 3, May 2007, pp. 431–53.

3 Barack Obama, speech, Prague, Czech Republic, 5 April 2009, http://www.whitehouse.gov/the_press_office/Remarks-By-President-Barack-Obama-In-Prague-As-Delivered/. In London four days previously, Presidents Obama and Medvedev had committed their 'two countries to achieving a nuclear free world'. The prime ministers of the United Kingdom and India, Gordon Brown and Manmohan Singh, and French President Nicolas Sarkozy, have made similar statements in the last 18 months.

4 Sharon Squassoni, *Nuclear Energy: Rebirth or Resuscitation?* (Washington DC: Carnegie Endowment for International Peace, 2009), http://carnegieendowment.org/files/nuclear_energy_rebirth_resuscitation.pdf.

5 George Perkovich and James M. Acton, *Abolishing Nuclear Weapons*, Adelphi Paper 396 (London: Routledge for the IISS, 2008), chapter 3. This Adelphi Paper is available on the Internet as section 1 of George Perkovich and James M. Acton (eds), *Abolishing Nuclear Weapons: A Debate* (Washington DC: Carnegie Endowment for

International Peace, 2009), http://www.carnegieendowment.org/files/abolishing_nuclear_weapons_debate.pdf. For the extreme view, that complete nuclear disarmament is impossible without the elimination of nuclear power, see Theodore B. Taylor, 'Nuclear Power and Nuclear Weapons', *Science and Global Security*, vol. 13, nos 1–2, 2005, pp. 118–28, http://www.princeton.edu/sgs/publications/sgs/pdf/13 1-2 Taylor-Feiveson.pdf. This article is significant because its author was a notable physicist and nuclear-weapons designer.

6 Natural uranium consists of 99.3% uranium-238 and 0.7% uranium-235. Enrichment is the process of increasing the proportion of uranium-235. Power reactors typically use uranium enriched to between 3% and 5% uranium-235; nuclear weapons typically use uranium enriched to more than 90%. Reprocessing is the chemical separation of plutonium from spent nuclear fuel. Reprocessing was originally developed for military purposes as part of the *Manhattan Project*. In the civilian sector, it was initially seen as a way of producing the plutonium needed to fuel fast reactors. In practice, most separated plutonium has either been left unused or burnt, probably uneconomically, in standard power reactors.

7 Heavy-water reactors are so called because heavy water (in which normal hydrogen is replaced by a heavier isotope, deuterium) is used to slow down or 'moderate' the neutrons in the reactor core. Most power reactors around the world today are light-water reactors and use normal water as the moderator. Gas-cooled reactors, which generally use carbon dioxide as the coolant and graphite as the moderator, are roughly as proliferation sensitive as heavy-water reactors but are much less important commercially.

8 'Fast' is a reference to the speed of neutrons in the reactor. Except for four prototype fast reactors, all other reactors in the world today use slower, 'thermal' neutrons. The interest in fast reactors lies in the fact that, depending on their mode of operation, they can either 'burn' the heavy, long-lived isotopes that complicate radioactive-waste disposal or can 'breed' plutonium to make more fuel.

9 The question of which are the most proliferation-sensitive technologies is not entirely settled. From a non-proliferation perspective, all nuclear technologies have some desirable and some undesirable attributes, and there is legitimate disagreement about the correct weighting of these. For a recent discussion of this issue see Harold Feiveson, Alexander Glaser, Marvin Miller and Lawrence Scheinman, 'Can Nuclear Power be made Proliferation Resistant?', Center for International and Security Studies at Maryland, July 2008, http://www.cissm.umd.edu/papers/files/future_nuclear_power.pdf. For a more technical discussion of proliferation-resistance methodologies see various papers in the special issue of *ESARDA Bulletin*, no. 39, October 2008, http://esarda2.jrc.it/bulletin/bulletin_39/index.html.

10 Indeed, this was suggested in the very first study on the control of atomic energy, the Acheson–Lilienthal report. See Chester I. Barnard, J.R.

Oppenheimer, Charles A. Thomas, Harry A. Winne and David E. Lilienthal, *A Report on the International Control of Atomic Energy* (Washington DC: Secretary of State's Committee on Atomic Energy, 1946), p. 42, http://www.fissilematerials.org/ipfm/site_down/ach46.pdf.

11 See GE Energy, 'Global Laser Enrichment', http://www.gepower.com/prod_serv/products/nuclear_energy/en/gle_main.htm.

12 A well-regarded 2003 study conducted by the Massachusetts Institute of Technology (MIT), for instance, estimates the total cost for nuclear electricity at $0.07/kWh, of which enrichment accounts for about 40% of the $0.005–0.006/kWh that is attributable to fuel-cycle costs (with no reprocessing) – that is, about 3% of the total. *The Future of Nuclear Power: An Interdisciplinary MIT Study* (Cambridge, MA: MIT, 2003), pp. 42, 143 and 146, available at http://web.mit.edu/nuclearpower/.

13 Compared to a centrifuge plant with a similar capacity, a laser-enrichment plant would use significantly less electricity and, because a single laser-enrichment module has a significantly higher 'separation factor' than a single centrifuge, be more compact. Moreover, the dual-use nature of the lasers used in the laser-enrichment process significantly complicates their control. Jack Boureston and Charles D. Ferguson, 'Laser Enrichment: Separation Anxiety', *Bulletin of the Atomic Scientists*, vol. 61, no. 2, March–April 2005, pp. 14–18, http://www.cfr.org/content/thinktank/Ferguson_BAS_separation.pdf.

14 Karl S. Coplan, 'The Externalities of Nuclear Power: First, Assume We Have a Can Opener …', Pace Law Faculty Publications, Paper 489, http://digitalcommons/pace.edu/lawfaculty/489.

15 According to the IAEA, no state 'is likely to have a repository in operation much before 2020'. Only Finland has actually started construction of a geological repository for high-level waste. IAEA, *Nuclear Technology Review 2008* (Vienna: IAEA, 2008), pp. 13–14, http://www.iaea.or.at/Publications/Reports/ntr2008.pdf. For quantitative estimates of the external costs see OECD Nuclear Energy Agency, *Nuclear Electricity Generation: What are the External Costs?* (Paris: OECD, 2003), http://www.nea.fr/html/ndd/reports/2003/nea4372-generation.pdf. Extraordinarily, this report fails to mention the word 'proliferation' even once.

16 Henry D. Sokolski, 'Towards an NPT-Restrained World that makes Economic Sense', *International Affairs*, vol. 83, no. 3, May 2007, pp. 531–48.

17 Intergovernmental Panel on Climate Change, *Climate Change 2007: Impacts, Adaptation and Vulnerability* (Cambridge: Cambridge University Press, 2007), pp. 821–23, http://www.ipcc.ch/ipccreports/ar4-wg2.htm.

18 *Ibid*, p. 17.

19 The Global Nuclear Energy Partnership (GNEP), launched in 2006, envisioned the United States sharing supposedly proliferation-resistant technologies, including reprocessing, with the handful of 'fuel supplier' nations that had already mastered the full fuel cycle. Other 'consumer'

nations, in return for comprehensive fuel services (that is, the provision of fresh fuel and the take back of spent fuel), were initially asked 'for their commitment to refrain from developing enrichment and recycling technologies'. Although this condition was quickly dropped once it became clear that no potential consumer state was willing to accept it, there were never plans to share sensitive technologies with them. See US Department of Energy, 'The Global Nuclear Energy Partnership: Greater Energy Security in a Cleaner, Safer World', 6 February 2006, p. 2, http://www.energy.gov/media/GNEP/06-GA50035b.pdf; and 'Global Nuclear Energy Partnership Statement of Principles', 26 September 2007, p. 1, http://www.gneppartnership.org/docs/GNEP_SOP.pdf.

20 Although the interest in nuclear power in the Middle East is partly a response to Iran, the extremely competitive nature of the various programmes clearly illustrates that prestige is also important. See International Institute for Strategic Studies, *Nuclear Programmes in the Middle East: In the Shadow of Iran*, IISS Strategic Dossier (London: IISS, 2008). For an amusing example of nuclear one-upmanship see Walter C. Patterson, 'Breeder Reactor Politics in Europe', *Bulletin of the Atomic Scientists*, vol. 42, no. 5, May 1986, p. 38, available at http://books.google.com/books?id=rQwAAAAAMBAJ.

21 A second factor is the desire to produce fuel for a nuclear-powered submarine – another classic prestige project.

22 Fuel-management policies are summarised in David Albright, Frans Berkhout and William Walker, *Plutonium and Highly Enriched Uranium 1996: World Inventories, Capabilities and Policies* (Stockholm: Oxford University Press for Stockholm International Peace Research Institute, 1997), Table 6.1.

23 Michael J. Brenner, *Nuclear Power and Non-Proliferation* (Cambridge: Cambridge University Press, 1982), p. 146.

24 For the United States see Brenner, *Nuclear Power and Non-Proliferation*, pp. 77–8. For the United Kingdom see Hon. Mr Justice Parker, *The Winsdscale Inquiry*, vol. 1 (London: Her Majesty's Stationery Office, 1978), para. 3.1.

25 Parker, *The Winsdscale Inquiry*, para. 9.1. Although Parliament, in a highly unusual move, voted on whether to proceed with the construction of THORP following the Windscale Inquiry, the inquiry is notable – and peculiarly British – for treating what most states would consider a key strategic decision as a local planning issue.

26 Sensible and important efforts to restrict the spread of the centrifuge have enhanced its prestige, for instance. It is telling that Brazil stresses the indigenous nature of its centrifuge programme, even though it is very likely based on imported technology.

27 In normal reprocessing, spent fuel is dissolved in acid and separated chemically. In pyroprocessing, spent fuel is dissolved in molten salt and separated by an electric current.

28 Interviews, Seoul, October 2008. Detailed calculations of the material flows in South Korea for various

fuel-cycle configurations are given in Emily Williams, *'Wait and See' No Longer? The Technical, Political, Economic and Nonproliferation Implications of South Korea and Taiwan's Spent Nuclear Fuel Dilemmas*, MA dissertation, King's College London, 28 August 2008.

29 Peter Hayes, 'The Republic of Korea and the Nuclear Issue', in Andrew Mack (ed.), *Asian Flashpoint: Security and the Korean Peninsula* (St Leonards, Australia: Allen and Unwin, 1993), p. 52.

30 Interviews, Seoul, October 2008. See also Selig S. Harrison, *Korean Endgame: A Strategy for Reunification and US Disengagement* (Princeton, NJ: Princeton University Press, 2002), p. 251.

31 There has been more legitimate sharing of this technology as well. See Houston G. Wood, Alexander Glaser and R. Scott Kemp, 'The Gas Centrifuge and Nuclear Weapons Proliferation', *Physics Today*, vol. 61, no. 9, September 2008, pp. 40–45, http://dx.doi.org/10.1063/1.2982121; and Frans Berkhout, Tatsujiro Suzuki and William Walker, 'The Approaching Plutonium Surplus: A Japanese/European Predicament', *International Affairs*, vol. 66, no. 3, 1990, p. 527.

32 IISS, *Nuclear Black Markets: Pakistan, A.Q. Khan and the Rise of Proliferation Networks: A Net Assessment*, IISS Strategic Dossier (London: IISS, 2007), pp. 18–20. Chapter 3 provides a description of the subsequent spread of the technology.

33 *Ibid*, pp. 47–50 and 58–89.

34 Specifically, Global Laser Enrichment states that 'the GLE process technology for laser enrichment of uranium involves classified and controlled information … Access to the technology requires a true "need to know", a "Q Clearance" (or the equivalent Department of Defense "Top Secret" clearance), and U.S. citizenship.' General Electric Hitachi Nuclear Energy, 'Technology Update: Global Laser Enrichment: Uranium Enrichment Using Advanced Laser Technology', June 2008, http://www.gepower.com/prod_serv/products/nuclear_energy/en/downloads/tech_update_june2008.pdf.

35 Geoff Brumfiel and David Cyranoski, 'Asia's Nuclear Family', *Nature*, vol. 423, no. 6936, 8 May 2003, pp. 110–11.

36 Interviews with an Iraqi nuclear-weapons scientist, London, 2006.

37 The technologies in question do not produce pure plutonium but instead leave it mixed with other isotopes, typically transuranics (elements heavier than uranium). However, the resulting material is not significantly harder for a state to weaponise, especially when compared to unreprocessed spent fuel. See, for instance, Jungmin Kang and Frank von Hippel, 'Limited Proliferation-Resistance Benefits from Recycling Unseparated Transuranics and Lanthanides from Light Water Reactor Spent Fuel', *Science and Global Security*, vol. 13, no. 3, 2005, pp. 169–81, http://www.princeton.edu/sgs/publications/sgs/pdf/13_3%20Kang%20vonhippel.pdf; and Edwin Lyman and Frank N. von Hippel, 'Reprocessing Revisted: The International Dimensions of the Global Nuclear Energy Partnership', *Arms Control Today*, vol. 38, April

2008, http://www.armscontrol.org/act/2008_04/LymanVonHippel.

38 Many non-nuclear-weapons states would probably argue that, apart from having a right to such technology, the proliferation costs of diffusing technology can be effectively managed with IAEA safeguards. Safeguards do lower proliferation costs. However, the limiting factor in ensuring compliance, now and in the foreseeable future, is not the efficacy of IAEA verification but the ability of the international community to respond effectively to non-compliance. Safeguards are therefore most effective when they provide the longest warning times of potential proliferation. They are least effective on the most sensitive nuclear facilities – those that can produce material that can be converted quickly into the explosive components of nuclear weapons (made from metallic highly enriched uranium or plutonium).

39 For example, Tariq Rauf and Fiona Simpson, 'The Nuclear Fuel Cycle: Is it Time for a Multilateral Approach?', *Arms Control Today*, vol. 34, December 2004, http://www.armscontrol.org/act/2004_12/Rauf.

40 Brenner, *Nuclear Power and Non-Proliferation*, pp. 149–51.

41 World Nuclear Association, 'Nuclear Power Reactors', April 2009, http://www.world-nuclear.org/info/inf32.html. The table lists the two LWR subdivisions, boiling-water reactors (BWRs) and pressurised-water reactors (PWRs), separately.

42 William Walker and Mans Lönnroth, *Nuclear Power Struggles: Industrial Competition and Proliferation Control* (London: George Allen and Unwin, 1983), pp. 23–5.

43 *Ibid.*, table 2.2; IAEA, *Nuclear Technology Review 2008*, p. 9.

44 Seven power reactors in Sweden (built by Asea Atom) and two in Finland (built by ABB) are derived from Swedish technology. The Chinese National Nuclear Corporation has built three power reactors in China and one in Pakistan, and a further three are currently under construction. World Nuclear Association, 'Reactor Database – Search', http://www.world-nuclear.org/rd/rdsearch.asp; Nuclear Threat Initiative, 'Qinshan Nuclear Reactors', 17 April 2004, http://www.nti.org/db/china/qinshan.htm.

45 Management Information Services, Inc., *Analysis of Federal Expenditures for Energy Development* (Washington DC: Management Information Services, Inc., 2008), p. 23, http://www.misi-net.com/publications/2008energyincentives.pdf. Converted into 2009 dollars.

46 Japan is a case in point. It is the OECD state most committed to fast reactors and, over the first half of this decade, its nuclear-energy research and development budget was about two-thirds of the OECD total. Nevertheless, Japan's breeder programme has consistently underperformed and is many years behind schedule. Its modestly sized Monju prototype reactor operated from 1994–95, when it suffered a coolant leak. The reactor has not operated since and its date for reopening (currently 2009) has been continually pushed back. Although Japan retains a strong rhetorical commitment to

the fast reactor, practical support has been waning (average annual funding dropped from $283 million in 1997–2001 to $148m in 2002–06) and the target date for commercialisation has now slipped back to 2050 (compared to a target of 2030 in 1994). 'Nuclear Power in Japan', World Nuclear Association, March 2009, http://www.world-nuclear.org/info/inf79.html; International Energy Agency, *Japan: 2008 Review*, Energy Policies of IEA Countries (Paris: OECD/IEA, 2008), p. 186. The situation in India, which also retains a very strong rhetorical commitment to the fast reactor, is broadly similar to that in Japan.

47 Dipka Bhambhani, 'DOE to End GNEP, Continue Research under AFCI', *Nuclear Fuel*, vol. 34, no. 8, 20 April 2009, p. 1.

48 For a useful summary of the evolution of US policy on reprocessing, see Anthony Andrews, *Nuclear Fuel Reprocessing: US Policy Development*, CRS Report for Congress, RS22542, 27 March 2008, http://www.fas.org/sgp/crs/nuke/RS22542.pdf.

49 Indeed, President George H.W. Bush even refused an application for the reprocessing of 100 tonnes of slightly irradiated US fuel abroad. For the background to this event see Matthew L. Wald, 'Shoreham's Nuclear Fuel May be Headed Abroad', *New York Times*, 23 September 1992, http://www.nytimes.com/1992/09/23/nyregion/shoreham-s-nuclear-fuel-may-be-headed-abroad.html.

50 Office of Nonproliferation and International Security (ONIS), *Draft Nonproliferation Impact Assessment for the Global Nuclear Energy Partnership Programmatic Alternatives* (Washington DC: ONIS, 2008), p. xii, http://nnsa.energy.gov/nuclear_nonproliferation/documents/GNEP_NPIA.pdf.

51 Reprocessing in Germany ended in 1990. UK reprocessing looks set to end at some point in the next decade. It is difficult, however, to demonstrate a causal link between the US moratorium and these closures.

52 William Walker, 'Entrapment in Large Technology Systems: Institutional Commitment and Power Relations', *Research Policy*, vol. 29, 2000, pp. 833–46.

53 Albert Wohlstetter, Thomas A. Brown, Gregory Jones, David McGarvey, Henry Rowen, Vincent Taylor and Roberta Wohlstetter, *Moving Towards Life in a Nuclear Armed Crowd?*, Final Report Prepared for US Arms Control and Disarmament Agency, ACDA/PAB-263 (Los Angeles: Pan Heuristics, 1975 [Revised 1976]), p. 15, http://www.albertwohlstetter.com/writings/NuclearArmedCrowd/.

54 The others are China, France, India, Japan, Pakistan, Russia, the United Kingdom and possibly Israel. In addition, the United States has kept the 'H Canyon' at the Savannah River Site open for some very small-scale operations. International Panel on Fissile Materials (IPFM), *Global Fissile Material Report 2008: Scope and Verification of a Fissile Material (Cutoff) Treaty* (IPFM, 2008), p. 11, http://www.fissilematerials.org/ipfm/site_down/gfmr08.pdf. Note that most of the planned programmes were dropped before the 1986 Chernobyl accident so that could not have been a factor.

55 IAEA, *Reprocessing, Plutonium Handling, Recycle,* Report of INFCE

Working Group 4 (Vienna: IAEA, 1980), Annex.

56 Interview with Italian nuclear analyst, via telephone, April 2009.

57 'Radioactive Waste Management Programmes in OECD/NEA Member Countries: Italy', Nuclear Energy Agency, http://www.nea.fr/html/rwm/profiles/Italy_profile_web.pdf.

58 Interview with Italian nuclear analyst, via telephone, April 2009.

59 The situation is remarkably similar to South Korea today and to Germany shortly before it abandoned reprocessing.

60 P. Venditti and G. Rolandi, 'Back End of the Nuclear Fuel Cycle: Italian Policy and Programmes', IAEA-SM-294/43, International Symposium on the Back End of the Nuclear Fuel Cycle: Strategies and Options, Vienna, 11–15 May 1987.

61 Interview with Italian nuclear analyst, via telephone, April 2009.

62 Jungmin Kang and H.A. Fiveson, 'South Korea's Shifting and Controversial Interest in Spent Fuel Reprocessing', *The Nonproliferation Review*, vol. 8, no. 1, Spring 2001, p. 72, http://cns.miis.edu/npr/pdfs/81kang.pdf.

63 Williams, *'Wait and See' No Longer?*.

64 Interview with South Korean nuclear officials, Seoul, October 2008.

65 It is not clear how credible this sanction is, given that it was not used on the past two occasions it could have been. When India tested a nuclear weapon in 1974, the United States continued to supply fuel to India's Tarapur reactor before finding an alternative supplier for its Indian client, France, in 1982. The contract was subsequently passed on to China and Russia. Similarly, Russia (with the eventual acquiescence of Washington) supplied fuel for the Bushehr Nuclear Power Plant in winter 2007–08 even though Iran had been found to be in non-compliance with its non-proliferation obligations. U.S. Committee on the Internationalization of the Civilian Nuclear Fuel Cycle, Committee on International Security and Arms Control, Policy and Global Affairs, and National Academy of Sciences and National Research Council, *Internationalization of the Nuclear Fuel Cycle: Goals, Strategies, and Challenges* (Washington DC: National Academies Press, 2009), pp. 36–8, available at http://books.nap.edu/catalog.php?record_id=12477; Peter A. Clausen, 'Nonproliferation Illusions: Tarapur in Retrospect,' *Orbis*, vol. 27, Fall 1983, pp. 741–59.

66 Joseph F. Pilat, 'Reliable Supply and the Global Nuclear Energy Partnership (GNEP)', Los Alamos National Laboratory, LA-UR-08-1619, [2008], http://www.lanl.gov/orgs/nso/docs/fy08/LA-UR-08-1619 Reliable Supply Global N.Energy.pdf.

67 In 2001, Russia changed the law to allow it to take back foreign-origin spent fuel. It now appears, however, to have lost interest in the idea. Lyman and von Hippel, 'Reprocessing Revisited'. France and, for the time being, Great Britain are willing to reprocess foreign spent fuel but will not keep the high-level waste produced.

68 ONIS, *Draft Nonproliferation Impact Assessment for the Global Nuclear Energy*

Partnership Programmatic Alternatives, p. xii.

69 Their argument is that the multiple waste streams produced by reprocessing complicate spent-fuel management. On this point the National Academy of Sciences concluded that the effect of reprocessing 'depends very much on the details of the burn-up, the waste streams, the waste forms, and the specific repository design and environment, so only a scenario-based approach to analysis works, and right now there is not enough information to know which scenarios are most likely'. *Internationalization of the Nuclear Fuel Cycle: Goals, Strategies, and Challenges*, p. 83.

70 The Yucca Mountain project was initiated in 1982 and was at least 22 years behind schedule when it was effectively abandoned by the Obama administration in 2009. Mark Holt, *Nuclear Waste Disposal: Alternatives to Yucca Mountain*, CRS Report for Congress, R40202, 6 February 2009, p. 2, http://www.fas.org/sgp/crs/nuke/R40202.pdf; *Program on Technology Innovation: Room at the Mountain: Analysis of the Maximum Disposal Capacity for Commercial Spent Nuclear Fuel in a Yucca Mountain Repository*, Technical Report 1015046 (Palo Alto, CA: Electric Power Research Institute, 2007), available at http://my.epri.com.

71 This phrase was used in discussions about importing *low*-level waste from Italy to the United States. Bart Gordon and Jim Matheson, 'Importing Nuclear Waste is in EnergySolutions' Best Interests, but not America's', *Salt Lake Tribune*, 5 April 2008, http://science.house.gov/Press/PRArticle.aspx?NewsID=2147. There were similar reactions to various proposals for Australia to host an international high-level nuclear-waste repository. See Ian Holland, 'Waste Not Want Not? Australia and the Politics of High Level Nuclear Waste', *Australian Journal of Political Science,* vol. 37, no. 2, July 2002, pp. 283–301; and 'Hawke Backs Aust as Nuclear Waste Repository', ABC News Online, 27 September 2005, http://www.abc.net.au/news/newsitems/200509/s1468931.htm.

72 This effect would be further exacerbated if a linkage is made to novel reprocessing schemes, such as UREX+ or pyroprocessing, that even advocates admit are decades away from commercialisation. See Holt, 'Nuclear Waste Disposal: Alternatives to Yucca Mountain', p. 17.

73 See, for example, Ian Hore-Lacy, 'Nuclear Power and Proliferation: A Nuclear Industry Perspective' in Perkovich and Acton (eds), *Abolishing Nuclear Weapons: A Debate*, p. 241–8.

74 Scott D. Sagan, 'Good Faith and Nuclear Disarmament Negotiations' in Perkovich and Acton (eds), *Abolishing Nuclear Weapons: A Debate*, pp. 203–10.