Irreversibility in Nuclear Disarmament

Practical steps against nuclear rearmament

David Cliff, Hassan Elbahtimy and Andreas Persbo

September 2011

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Foreword

Over the last decade, the term 'irreversibility' has entered the lexicon of nuclear disarmament. It was introduced into the Nuclear Non-Proliferation Treaty (NPT) framework at the NPT's 2000 Review Conference—both as a practical measure applying to nuclear material no longer needed for military purposes and as a general disarmament principle. This concept of irreversibility was ushered into the multilateral process seeking to denuclearize the Korean peninsula and found its way into diverse multilateral documents. It is steadily becoming a mainstream notion, often appearing alongside mentions of verification and transparency.

Yet, whereas the issues of verification and transparency have been the subject of numerous studies, assessments and proposals regarding implementation, the concept of irreversibility has undergone very little scrutiny and remains largely understudied. No agreed-upon definition of what it means and what it entails exists. It remains vague and may even mean different things to different people. As a result, the practical utility of this concept in supporting nuclear disarmament remains limited. Its potential seems to have been far from fully explored.

It is with these elements in mind that the Swiss Federal Department of Foreign Affairs (FDFA) set out to further the concept of irreversibility in nuclear disarmament, at both the theoretical and practical levels.

The FDFA commissioned two studies on irreversibility in nuclear disarmament. VERTIC developed a study focusing on the conceptual, technical and operational aspects of the question. SIPRI drafted a study addressing the political, societal, legal and military-technical dimensions of the issue.

The aim of these studies is to make up for some of the shortfall surrounding the concept of irreversibility. Their aim is to stimulate thought, debate and action, to challenge readers and to introduce new approaches and options. They have been drafted with several audiences in mind: disarmament practitioners, government officials and diplomats, nuclear weapons designers, policy analysts and academics, NGO representatives and the wider public.

The process that led to the publication of these two studies on irreversibility also included a workshop held in Glion, Switzerland, in February 2011. The objective of this gathering was to discuss an initial draft of the VERTIC study, as well as to further explore the issue as a whole. We are thankful to all the participants of that meeting. The wide range of government officials and representatives from the academic and non-governmental world made for thorough and productive discussions. The final version of the two irreversibility papers benefited greatly from the input of all participants.

What the discussions in Glion and the two studies commissioned by the FDFA have shown is that irreversibility is both a key concept and a vast, complex subject. It covers many areas, has received too little attention thus far and its potential remains largely untapped. The two studies provide indications as to what measures would reinforce the irreversibility of nuclear disarmament. It is hoped that they will lead to further work on this issue and spur action at many different levels.

Executive Summary

The aim of this study is to examine and develop the concept of irreversibility as it relates to nuclear disarmament. While the word is becoming increasingly used in discussions over nuclear disarmament, its meaning in this particular context remains largely undefined and understudied. In particular, the kind of specific steps that would need to be taken to arrive at a level of disarmament irreversibility have not, to date, been given much consideration.

This report argues that the dictionary definition of irreversibility is not well-suited to the context of nuclear disarmament and that, for the purposes of nuclear disarmament, an understanding of irreversibility more suited to the reality of possible nuclear reversal is needed. As a result, *this report views irreversibility in terms of the costs and difficulty of reversal.* Irreversibility thus becomes a scale—not the binary state implied by dictionary definitions of the term—with readily reversible actions at the low end and measures that are highly difficult and costly to reverse at the other.

Nuclear disarmament itself is not a binary state. A country can be disarming while not being yet fully disarmed. The process to achieve the final abolition of an entire class of weaponry may still be called disarmament. But weapons can always be produced. Even a fully-disarmed state can rearm if there is the political will and the resources to do so. A state that controls the raw materials, the necessary industrial infrastructure, and technical and scientific knowledge will always be able to hedge against the loss of nuclear weapons capacity. All disarmament actions are, therefore, reversible. But some are more easily reversible than others. In nuclear disarmament, it may be rather more suitable to talk about *unarmed states* rather than *disarmed states*.

This report follows the literal definition of disarmament as a state in which the process of disarming has been fully completed and no nuclear weapons remain. It focuses on locking-in an *end-state* of nuclear disarmament, and not on the process of getting to zero via nuclear arms reductions. The focus of this report is on the practical and technical aspects of securing that end-state—not on the wider societal, political and legal aspects of irreversible disarmament, which are the subject of a parallel study by the Stockholm International Peace Research Institute (SIPRI).[1]

This report indicates that if all nuclear warheads in a country were dismantled then the irreversibility of that disarmament would depend, above all, on the following:

- The amount of weapons-usable fissile material in the state in the form of intact (and unstuffed) pits; and, thus, able to be directly used—or re-used, as the case may be—in warheads;
- The amount of weapons-usable fissile material in the state in forms not immediately able to be implanted in weapons (i.e. in non-pit form, whether that material is safeguarded or not);
- The capabilities of the state to produce weapons-usable fissile material and, separately, to fabricate that material into pit forms that can be implanted into warheads;

1 See *Irreversibility in Nuclear Disarmament—Political, Legal, Societal and Military-Technical Aspects,* SIPRI 2011.

- The existence or absence of warhead assembly facilities within the state, where pits and the various non-nuclear components of a warhead would be combined; and
- The availability of delivery systems that could deliver warheads to a target in a reliable fashion.

Short of the abandonment of all nuclear infrastructure, a state towards the 'high' end of the irreversibility spectrum will be one without any means whatsoever to produce nuclear weaponry. This would require that the following steps are fully implemented:

- The destruction of the fissile material components of dismantled warheads;
- The disposition of all weapons-usable fissile material within a state (i.e. not just those from weapons);
- The elimination, disablement or conversion to civil uses of all facilities involved in the final assembly of warheads and the manufacture of warhead pits;
- The elimination, or the severe disablement, of all facilities used in the production of potentially weapons-usable fissile materials (i.e. enrichment and reprocessing plants);
- The placement of all fissile materials under international safeguards; and
- The elimination or conversion to non-nuclear roles of all nuclear delivery vehicles.

Cumulatively, the above steps would make the process of nuclear rearmament costly, difficult, time-consuming and more than likely to be detected by the international community. It therefore entails a high degree of irreversibility, in terms of costs and difficulty. It should be noted, however, that the range of possible 'end states' (of which the measures contained in above list form just one) is vast—as are the consequent implications for irreversibility. This report has sought to convey the complexity of this issue, while also simplifying it to the extent that the principal factors can be usefully analysed and conclusions drawn.

Many of the steps outlined in this report are framed in post-disarmament terms. But not all necessarily require a country to be fully disarmed before they can begin to be implemented. Taking steps to limit, reduce and control stocks of weapons usable fissile materials—or to eliminate the means of their production (i.e. enrichment and reprocessing facilities), perhaps through incentivising multilateral fuel cycle arrangements—are all steps that could be taken today with a view to aiding disarmament irreversibility in the future. For that matter, since the dismantlement of warheads is one of the central pillars of this report, its incorporation into future arms reduction treaties help not only the short-term irreversibility of any such agreements but perhaps also set a precedent for other accords besides.

The 'endurance of knowledge' of nuclear weaponisation and the impact of verification are, of course, critically-important factors also. Knowledge and expertise provide a link between nuclear technology and materials and a workable nuclear explosive device. Verification has already been mentioned above in the context of international safeguards on fissile materials. But verification and monitoring can go far beyond safeguards and, if such measures function properly as a deterrent, then they can play a key role in changing the calculations of states over rearmament decisions.

1. Introduction

Over the last few years, nuclear disarmament has been the subject of increasing political attention. This, coupled with continued cuts in nuclear arsenals, has arguably led to an increased sense that nuclear disarmament—the point of zero—is no longer such a remote and unachievable goal. Clearly, however, there is much more that can be done with regard to the implementation of disarmament obligations.

In 2000, five years after the disarmament norm embedded in the Nuclear Non-Proliferation Treaty (NPT) was extended indefinitely, the NPT Review Conference outlined 13 'practical steps' toward nuclear disarmament. One of those was the principle of irreversibility. In the years since the 2000 conference, 'irreversibility' has remained within the lexicon of nuclear disarmament—appearing in a host of speeches, policy statements and official documents. Indeed, the final document of the 2010 NPT Review Conference contains a commitment by the treaty's 189 parties 'to apply the principles of irreversibility, verifiability and transparency in relation to the implementation of their treaty obligations.'

The aim of this study is to examine and develop the concept of irreversibility as it relates to nuclear disarmament. While the term is becoming increasingly used in discussions over nuclear disarmament, its meaning remains largely undefined and understudied. In particular, what specific steps would need to be taken to arrive at a level of disarmament irreversibility have not, to date, been given much consideration. Moreover, now that the nuclear weapons 'genie' has been released from its bottle, can disarmament *ever* be irreversible anyway? Is the term, in this particular context, fundamentally undermined by the improbability that the knowledge of nuclear weapons and of how to build them will ever be truly forgotten?

This study is focused on the technical elements of irreversible nuclear disarmament and on locking-in an end-state of nuclear disarmament. The authors recognise, however, that the technical steps outlined in this report do not exist in a political and social vacuum—and that any and all such influences will weigh heavily on considerations of both disarmament and irreversibility. And though this report focuses on the end-state of disarmament, the authors recognise that considerations of irreversibility will play an important part in the route to zero. A companion study by the Stockholm International Peace Research Institute (SIPRI), also commissioned by the Swiss FDFA, examines the various political, societal, legal and military-technical factors associated with irreversible nuclear disarmament in greater detail. The SIPRI study leaves the technical aspects of irreversibility to one side, explicitly focusing on these other aspects—which, in keeping with VERTIC's more technical focus, the authors of this report have chosen not to address.

This study begins by examining the meaning of irreversibility and how to define it. It looks at the common understanding of the term as specified in the Oxford English Dictionary and its applicability in the context of nuclear disarmament. How can the widely understood and commonly-accepted dictionary definition of irreversibility be applied to the nuclear disarmament field?

This report argues that, for the purposes of nuclear disarmament, an understanding of irreversibility more suited to the reality of possible nuclear reversal is needed. As a result, *this report views irreversibility in terms of the costs and difficulty of reversal.* Irreversibility thus becomes a scale—not the binary state implied by dictionary definitions of the term—with readily reversible actions at the low end and measures that are highly difficult and costly to reverse at the other.

Starting from the end state of disarmament as the point at which a state has done away with its nuclear weapons, this study goes on to look at what—in terms of tangible, practical steps—could be taken to make that state of disarmament as irreversible as possible. What dismantlement actions could be implemented on warheads, for instance, and what protocols could be put in place at various parts of a state's nuclear warhead production complex in order to ensure certain levels of irreversibility. And what, furthermore, are the implications of irreversibility on verification.

With regard to verification, this report argues against the common conception of irreversibility as being closely, almost inexorably, linked to verifiability and transparency. Often, verification and irreversibility are presented as being two sides of the same coin. But this, we argue, is something of a mischaracterisation of the role and function of verification. More properly, *verification should be seen as complementary to irreversibility*. Verification measures can play an important role in helping to deter reversals, through the consequences likely to follow from detection, but monitoring cannot—in and of itself—prevent any such actions being taken. In the chapters that follow, this report aims to make this distinction clear.

Later in the report, the lessons learned from the theoretical and case study analysis are applied to various hypothetical states pursuing nuclear disarmament. The purpose of this analysis is to explore options for various levels of irreversibility that are potentially applicable to different kinds of countries and fuel cycles. The three hypothetical scenarios constructed for this chapter were chosen as representative of various categories of nuclear-armed states countries that might be encountered in the real world.

The range of possible variations within these categories, however, can be vast. To investigate each and every possible fuel cycle and warhead production complex, and every possible combination of disarmament measures, would be near to impossible. Thus, in developing the scenarios for this chapter, the aim was to invent hypothetical states and fuel cycles that were broad enough to allow for a more comprehensive discussion of the various options for disarmament—and their implications for irreversibility—that could be implemented.

In support of the theoretical analysis of irreversibility, this report draws on a number of historical case studies, including: nuclear arms control agreements between the US and Russia (or the Soviet Union); nuclear 'freezing' and 'disablement' in North Korea; the Libyan renunciation of nuclear and other weapons of mass destruction; and the verified dismantlement (albeit after the fact) of South Africa's nuclear arsenal. None of these case studies are perfectly suited to studying disarmament irreversibility. Indeed, on the one hand they serve to illustrate the *lack* of serious attention paid to irreversibility in past practice. In the US-Russian context, for instance, no treaty has yet been agreed requiring the two countries to dismantle even one warhead. And even in the North Korean case, disablement actions taken at its Yongbyon site were designed to prevent the DPRK from restarting facilities by around one year—hardly an irreversible setback.

Consequently, the case studies are not used to provide a textbook example of how to conduct irreversible nuclear disarmament, since they are plainly ill-suited for this purpose. Rather, they are used to explore the various elements that need to be addressed, and various ways to address them, in the pursuit of high levels of irreversibility. All encompass strands of thinking and practice that this report has attempted to weave into a coherent whole. These case studies form annexes to this report, though their influence is felt throughout.

2. Analytical Overview

This report seeks to examine, within the context of nuclear disarmament, the concept of irreversibility. The term is one that is beginning to appear increasingly in disarmament literature and policy statements, but about which little has been studied and not much in the way of specifics is known. This report begins by identifying a way of understanding irreversibility that is more suitable for the disarmament context than the emphasis on permanence found in dictionary definitions of the term. It is difficult to imagine how nuclear disarmament could ever be completely irrevocable. Therefore, this report views irreversibility as a scale, with readily reversible steps at one end and a difficult to reverse 'end state' at the other.

This report draws on lessons learned from an investigation of case studies including: US-Russian nuclear arms treaties; nuclear freezing and disablement in North Korea, disarmament in Libya; and warhead dismantlement verification in South Africa. Each of these case studies—which are set out in full in the four annexes to this report—has informed our analysis in various ways and helped us to reach the conclusions that we have arrived at. In addition, the conclusions drawn in this first chapter are used subsequently in the report to theorise how hypothetical states can be disarmed to varying levels of irreversibility. The report has a closing chapter, in which the main points are reiterated and where areas that may benefit from further study are highlighted.

2.1 Introduction

Calls for nuclear disarmament are as old as the age of nuclear arms itself. There were fewer complicating factors standing in the way of disarmament in those early days of the late 1940s, though. Then, as the 2009 report of the International Panel on Fissile Materials (IPFM) noted, there was just one nuclear-armed state, with only a small arsenal of nuclear bombs. 'Long-range missiles had not been developed, civil applications of nuclear energy lay in the future, and the bureaucratic, military, industrial and doctrinal complexes and many of the rationales and justifications that would be erected around nuclear weapons during the Cold War had yet to come into being.'[2] But the onset of ideological rivalry between the US and the Soviet Union, the arms race that followed and the gradual entry of new states into the nuclear 'club', saw disarmament prospects fade further and further into the distance.

Despite substantial reductions in the number of nuclear weapons in existence since the end of the Cold War, there are still many thousands of nuclear weapons around the world—albeit held predominantly by the US and Russia—today. After a period of little movement on the downsizing of nuclear arsenals, however, recent years have seen a renewed level of interest and of cautious hope in disarmament prospects. The vision of a world free of nuclear weapons was endorsed by US President Barack Obama in his seminal 'Prague speech' in May 2009. His commitment to disarmament has most recently resulted in the ratification of a new US-Russian treaty on strategic nuclear arms reductions.

2 International Panel on Fissile Materials (IPFM), *Global Fissile Material Report 2009: A Path to Nuclear Disarmament*, IPFM, 2009, 25.

In putting together this report, the dual meaning of the word 'disarmament'—i.e. the way it can be variously used to describe both processes and end states—was encountered many times. In the *Encyclopedia of Arms Control and Disarmament*, Richard Burns notes that the term has historically tended to be used to refer to 'efforts to limit, reduce or control the implements of war,' and that: 'While linguistic purists might employ *disarmament* in the literal sense—that is, the total elimination of armaments and armies—most diplomats and commentators have not.'[3] In this report, the term 'disarmament' *is* used in the literal sense; that is, to refer to a point at which no nuclear weapons continue to exist within a given state. In other words: a state where 'nuclear disarmament' has taken place is, for the purposes of this paper, a state wherein no nuclear weapons remain.

2.2 Understanding irreversibility

Taken on its own, the word 'irreversible' has one distinct meaning. However, little effort has been invested into attempting to understand how the meaning changes when the term is combined with the term 'disarmament'. The phrase 'irreversible disarmament' remains mostly unexplored. This provokes a number of interesting, and challenging, questions. For instance, to what extent can the commonly understood, everyday meaning of irreversibility apply to nuclear disarmament? What modifications to that meaning, if any, are required? Or, alternatively, is it possible to come up with a new definition altogether—one more specifically tailored to suit the subject matter at hand?

According to the 1989 edition of the *Oxford English Dictionary*, the English word irreversibility, or the 'character or quality of being irreversible', refers to that which 'cannot be undone, repealed, or annulled', nor 'turned backwards, upside down, or in the opposite direction.'[4] By these definitions, an irreversible step—or process, or change—is one that is inherently irrevocable: one that entails no possibility of reverting to the prior position or original state of being.

There are, though, real challenges in transposing the dictionary definition of irreversibility into the nuclear arms control and disarmament discourse. For one, its strong emphasis on the irrevocable and assured seems at odds with the possibility that states can decide to re-arm. In addition, many argue that we will always live under the shadow of nuclear weapons. The knowledge needed to produce these arms is likely to endure for many, many generations beyond the point at which the world's last explosive nuclear device is destroyed. Moreover, although one can imagine getting rid of all nuclear arsenals that exit today, the scientific and technical infrastructure that helped bring nuclear weapons in the first place will likely remain. This is particularly challenging since an increasing number of states are starting to rely on nuclear science and engineering to produce cheap and clean energy.

All this has driven analysts to either outright dismiss the possibility that irreversible nuclear disarmament can be achieved or resign themselves to the vagueness associated with the undefined use of the term in the current discourse. Serious examinations of irreversibility might also have been hampered by the slow pace of nuclear arms reductions. Sluggish progress in reducing nuclear armaments does not provide compelling reasons to look at the problems of nuclear rearmament. Added to this, while nuclear disarmament can be conceived of as an end-state, the world conditions that will accompany it (and hence influence re-armament) are more difficult to assertively gauge.

3 Richard Dean Burns, 'An Introduction to Arms Control and Disarmament', in the *Encyclopedia of Arms Control and Disarmament: Volume I*, Charles Scribner's Sons publishers, 1993, 2.

4 J.A. Simpson and E. S. C. Weiner, *The Oxford English Dictionary Volume VIII* 'Interval—Looie', 2nd edition, Oxford University Press, 1989, 100.

To be useful within the context of nuclear disarmament, a more practical, functional meaning of irreversibility is required. Such a definition would better take into account the underlying possibility, and reality, that formerly nuclear-armed states could reconstitute their nuclear arsenals with the capabilities and knowledge that they retain. *In the nuclear disarmament context, it may therefore be more appropriate to consider irreversibility in terms of the costs and difficulty of rearmament.* As the respected law professor Cass Sunstein has written (with regard to irreversibility in environmental and public health matters), 'the question is not whether some effect can be reversed, but instead at what cost.'[5] As applied to nuclear disarmament: the question is not whether disarmament can be reversed, but how costly—and, by the same token, how difficult—would it be to do so?

From that analysis, it is possible to conceive of irreversibility in the context of nuclear disarmament in terms of a scale. At the lower end reside readily reversible measures, for instance those that only address the nuclear explosive devices themselves. At the other end lies complete denuclearisation, i.e. the most costly and difficult (and time-consuming) to undo. A vast, almost endless, number of possible scenarios reside at various points along the scale.

2.3 The significance of irreversibility

In terms of the significance of steps to promote disarmament irreversibility, the political function is perhaps the most readily apparent—and perhaps also the most intangible. A state taking steps to render its disarmament as difficult to reverse as possible would present to the international community a greater degree of commitment to nuclear disarmament than would be the case otherwise.

However, the most *important* consequence of strong irreversibility measures is arguably the potential impact on threat assessments and predictability. If a state is able to estimate how long it would take to rebuild and re-deploy a certain number of nuclear weapons, then a certain measure of predictability arises. Depending on the kind of steps taken, and the confidence of predictions (where verification would likely come into play), the knock-on effect on stability could be significant.

2.4 Irreversibility and nuclear deterrence

Counter-intuitively, one can also make the argument that the ability to reverse disarmament positively contributes to efforts to achieve nuclear abolition. If disarmament *was* irreversible then nuclear-armed states may be more reluctant to pursue it. After all, they would be doing so knowing that they could never go back on abolition if at some point in the future they deemed it necessary or desirable to do so.

Along these lines, in 1984 Jonathan Schell argued that the knowledge of how to rebuild nuclear weapons 'would keep deterrence in force.'[6] As Schell argued, any disarmed state 'considering possible nuclear breakout would be restrained by the prospect that others could quickly follow suit.'[7] Put another way: in a world where nuclear weapons have been abolished a degree of inherent stability would exist among states. Should one move toward rearmament, other former nuclear-armed powers would be able to restock their own arsenals in turn, meaning that no one state would be able to gain a decisive advantage. The world, as Barry Blechman has written, 'would be no worse off than it is now.'[8]

5 Cass R. Sunstein, 'Irreversibility', Oxford University Press, Law, Probability and Risk, Forthcoming; Harvard Public Law Working Paper No. 08-25; Harvard Law School Program on Risk Regulation Research No. 08-1, 2008, 9.

6 IPFM *Global Fissile Material Report 2009*, 29.

7 IPFM *Global Fissile Material Report 2009*, 29.

8 Blechman, 'Why we need to eliminate nuclear weapons—and how to do it', 10.

Moreover—as James Acton and George Perkovich have noted—in making a case for 'weaponless deterrence' Schell argued not only that former nuclear-weapon states would retain the knowledge needed to rebuild their nuclear arms but that they should also actively maintain, or be permitted to maintain, the capabilities (including fissile material stocks, trained workers and production facilities) to produce those weapons at short notice.[9] And as a National Academy of Sciences (NAS) report on *The Future of US Nuclear Weapons Policy* postulated in 1997: 'Allowing states to maintain the capacity to rebuild nuclear weapons also would diminish the incentive for states to keep a few concealed nuclear weapons as a hedge against the possibility that others might do the same.'[10]

If capabilities remained, in the event of attempted rearmament by one state other 'virtually' nuclear-armed states would be able to quickly reconstitute nuclear arsenals of their own in response. Indeed, as Zia Mian has observed, the Obama administration's Nuclear Posture Review, released in March 2010, has essentially incorporated this point into official US nuclear weapons policy. The posture review states that a 'modern nuclear infrastructure' and a 'highly skilled workforce' of nuclear weapon designers, engineers and technicians will be needed 'even in a world with complete nuclear disarmament'. As argued by the review: a 'robust intellectual and physical capability would provide the ultimate insurance against nuclear break-out by an aggressor.'[11]

On the other side of this debate, though, are the arguments that 'virtual' arsenals are not a sensible—nor even a particularly feasible—idea. 'First, allowing states to maintain the capability to build nuclear weapons on short notice would make it easier to cheat while at the same time making it more difficult to detect cheating,' the NAS observed in 1997. 'Permitted weapons-related activities would be of great value for a clandestine programme and would create a background of legal activity against which it would be more difficult to detect illegal activities.' Furthermore, the NAS argued, 'having states poised to resume manufacture and deployment of nuclear weapons could create dangerous instabilities in which states might rush to rearm during a crisis,' thereby worsening the situation.[12]

Another potential problem, anticipated by Acton and Perkovich, relates to the adequacy of resources. As they note, 'given that weapons establishments are worried even today about the loss of expertise and difficulty of recruiting and retaining skilled staff, for how long would they be in a position to deploy the human, financial and technical resources necessary to maintain effective virtual nuclear arsenals in a denuclearising world?'[13]

Then there is the question of whether virtual nuclear arsenals might be vulnerable to attack and destruction by conventional arms. 'For Schell's concept of weaponless deterrence to work,' Acton and Perkovich have written, 'it must be effectively impossible for one state to destroy another's nuclear weapons complex.'[14] How to reconcile this need for protection with an almost inevitable need for verification—which would almost unavoidably reveal the location and purpose of particular sites—is not an easy task by any means.

2.5 Disentangling verification and irreversibility

The final document of the 2010 NPT Review Conference noted the collective agreement of parties 'to apply the principles of irreversibility, verifiability and transparency in the implementation of their treaty

9 George Perkovich and James M. Acton (eds), *Abolishing Nuclear Weapons: A Debate*, Carnegie Endowment for International Peace, 2009, 120.

10 National Academy of Sciences, *The Future of U.S. Nuclear Weapons Policy*, National Academy Press, 1997, 91–92.

11 Zia Mian, 'Charting a path toward eliminating nuclear weapons', *Bulletin of the Atomic Scientists,* 27 September 2010.

12 National Academy of Sciences, *The Future of U.S. Nuclear Weapons Policy,* 92.

13 Perkovich and Acton, *Abolishing Nuclear Weapons*, 121.

14 Ibid.

obligations.'[15] Indeed, mentions of irreversibility in disarmament literature and policy statements tend in general to be closely tied to mentions of verification, verifiability or transparency.

There is, though, a need to disentangle verification from irreversibility. Certainly, verification measures can play an important role in increasing confidence that 'irreversible' steps have been taken, and adhered to, but *verification does not by any means ensure irreversibility*. Nor is it designed to. The role of verification is to provide assurances that certain steps have been taken as declared (i.e. that a party has done what it said it would), to detect violations and to deter, through the risk of detection and the punitive measures that might result from detection, any such violations in the first place. Thus, while verification *might* be able to detect steps toward rearmament—and to deter those steps from being taken at all—it would not, in and of itself, be able to prevent them. As a result, for verification to function properly, verification measures need to be backed up with penalties for violators.

Where verification has arguably the most value, though, is in allowing states with every intention of disarming in an irreversible fashion (to some extent or other) to advertise their actions to the wider international community, and in so doing to gain greater international credibility as a state opposed to nuclear weapons and their destructive power. Consider the case of South Africa, where invited inspectors from the International Atomic Energy Agency (IAEA) verified in the early 1990s that the small South African atomic arsenal had been destroyed as declared.

2.6 Irreversibility in its socio-political context

As noted in the Introduction chapter, this report is focused on the technical side of disarmament irreversibility. That is: what specific and tangible actions can be taken to make rearmament progressively more difficult and financially costly, starting with the dismantlement of warheads and moving towards the complete abandonment of all nuclear infrastructure within a formerly nuclear-armed state.

This report is also focused on locking-in an *end-state* of nuclear disarmament—*not on the process of getting to zero* via nuclear arms reductions. During the reductions phase, unless all capabilities to manufacture weapons-usable fissile materials and nuclear warheads are removed, reversibility will primarily be a matter of political will. While a state is still in possession of one or a number of nuclear weapons it cannot, by definition, said to have reached a state of disarmament.

During the disarming phase, however, there is nothing to stop many of the steps outlined in this report being taken to reduce the capabilities of a state to manufacture nuclear warheads. Indeed, *the more practical steps that are taken during the disarming phase, the simpler it will be to reach a high level of irreversibility once all weapons are dismantled*. For instance, while undertaking a process of nuclear arms reductions a state may decide to also abandon any facilities used for enriching and/or reprocessing nuclear material. That would complicate any later efforts to produce new quantities of weapons-usable fissile material.

As noted earlier, however, the technical nature of this report does not, by any means, seek to suggest that the practical steps outlined exist in a political and societal vacuum. These factors, along with legal and military-technical issues, are addressed fully in the SIPRI study on irreversible nuclear disarmament that forms a companion paper to this report. Here, it is sufficient to note that political, socio-cultural, legal and other factors all have significant parts to play in ensuring that a state of disarmament is not reversed—and in reaching that state in the first place. Indeed, the cumulative normative effect of such

15 2010 Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons Final Document, NPT/CONF.2010/50 (Vol. I), 20.

pressures against producing and possessing nuclear weapons, when combined with practical, technical steps to complicate rearmament, is likely to help ensure that a disarmed state remains so.

If a change of leadership, or the rise of an existential threat to a state, was to shift that normative opposition to the possession of nuclear weapons in the other direction, however, the principal barriers to rearmament would likely be technical (and financial) ones. If a political decision to begin rearmament was taken, with the support or tacit consent of the people of that state, then one of the main obstacles to rearmament would be whatever actions had previously been taken to lock-in disarmament and make its reversal as difficult and as costly as possible.

Thus, actions such as the prompt disposition of weapons-usable fissile materials and the elimination of enrichment and reprocessing facilities are best taken as soon as possible—before disarmament is reached even.

As a hypothetical example, it may be instructive to consider a scenario in which a state has abandoned all its nuclear weapons, only to decide to rebuild them one year later (following a change of political leadership perhaps). Within that one-year period, the decision to eliminate stocks of weapons-usable fissile material and all enrichment and reprocessing facilities may have been taken but it is unlikely that there would have been sufficient time to implement such steps. *But*, if stocks of weapons-usable fissile material had been eliminated as nuclear arms reductions progressed (leaving only a few remnants of weapons-usable fissile after the last warheads were dismantled), and if enrichment and reprocessing facilities were eliminated years or maybe decades before, then the opportunity for the prompt reconstitution of the state's nuclear arsenal one year on from disarmament would not exist to nearly the same extent.

2.7 Disarmament 'end states' and irreversibility

When thinking about nuclear disarmament, and particularly when those thoughts run alongside thinking about irreversibility, it is instructive to consider that there are two different aspects of a state's nuclear arsenal that disarmament measures can theoretically address:

- First, the *current nuclear arsenal* of any given nuclear-armed state; and
- Second, the *supporting infrastructure* that could potentially be drawn on to produce more weapons in the future.

With regard to the first of these two aspects, the functional units of a state's current nuclear arsenal are the nuclear weapons in its possession. As the UN Department of Disarmament Affairs noted in a 1991 study of nuclear weapons, the essential part of all such weapons is their nuclear explosive component—or warhead—within which fissile materials with explosive potential are arranged. Nuclear warheads may be fitted in or on to various kinds of delivery vehicles (such as missiles, gravity bombs, artillery shells and so forth), with the term 'nuclear weapon' usually denoting the combination of both.[16]

Nuclear warheads do not exist in isolation, however.[17] Rather, they are supported by a potentially vast nuclear infrastructure including fissile material production plants, weapons assembly facilities and other sites that collectively form what is generally referred to as a state's nuclear warhead production complex.

That said, more than just physical facilities and materials are needed for the production of nuclear warheads. Knowledge is needed also. Indeed, knowledge and understanding of the science underpinning

16 UN Office of Disarmament Affairs (UNODA), *Nuclear Weapons—A Comprehensive Study*, UNODA, 1991, 11.

17 Except, perhaps, in various hypothetical cases of black market procurement.

nuclear processes and (even more critically) of how to weaponise nuclear materials represents one of the most essential components of the requirements needed to produce and maintain a functional nuclear arsenal. *Without weaponisation knowledge, a state might have—or have access to—all the necessary physical parts of a nuclear warhead, but still be unable to fit them together into a workable explosive device.*

2.7.1 Building upon a disarmament 'minimum'

In 1996, in a paper on 'Verifying Nuclear Disarmament', Steve Fetter wrote that: 'At a minimum, disarmament would require the dismantling of all nuclear explosive devices under national control.'[18] Following this—also literal—definition of disarmament, for any given state to have been 'disarmed' of its nuclear weapons capability, whether voluntarily or not, it would need to have dismantled its entire *existing* arsenal of nuclear warheads.

For Fetter, then, the critical security consideration for disarmament purposes is the nuclear warhead component of a nuclear weapon, as opposed to those weapons' delivery vehicles. In theory, the utility of a state's nuclear warheads could be negated, or at least severely impeded, by the elimination of all its nuclear-capable delivery vehicles. In practice however, as is explored in greater depth below, that is a far from straightforward undertaking.

By Fetter's definition, reaching zero nuclear warheads achieves a minimum level of disarmament. The capabilities of the state to produce new weapons remain intact. Clearly, in such circumstances there is room for more wide-ranging action.

Building upon Fetter's disarmament minimum, and leaving aside (for now at least) what might be called the 'endurance of knowledge' problem, one might posit a considerably 'higher' level of disarmament to involve measures directed toward both a state's current warhead stockpile *and* measures to address its supporting nuclear warhead production complex. A 'high' level of disarmament would likely also include the elimination or conversion of a state's nuclear delivery vehicles.

In terms of irreversibility, then, addressing only the current warhead stockpile of a state is likely to be readily reversible if the supporting infrastructure—i.e. the capabilities to reassemble warheads or make new ones—is left untouched. In such instances, assembly and production facilities could simply rebuild or replace warheads or warhead components lost or rendered unusable as a consequence of disarmament actions. By contrast, *addressing a state's nuclear warhead production complex in addition to its existing warhead stockpile would provide for a far greater degree of disarmament irreversibility, since warheads could not be indigenously reproduced without first reconstituting the capabilities to construct them.*

Indeed, it is this point that highlights the existence of a strong link between disarmament irreversibility and the need to address not only those warheads currently in a state's possession, but the capabilities of a state to produce such devices in the first place—and possibly also in the future.

Thus, to add more in the way of specifics to what was said above, for any given nuclear-armed state, a 'high' level of disarmament might entail:

- The dismantlement of all nuclear explosive devices and/or nuclear warheads;
- The destruction—possibly by way of conversion to non-weapons-usable forms—of their fissile material components;
- The elimination, disablement or conversion to civil uses of facilities involved in the final assembly of nuclear warheads, as well as those involved in the fabrication of key warhead components (especially fissile 'pits') and the production of fissile material for weapons purposes;

18 Steve Fetter, 'Verifying Nuclear Disarmament', *Henry L. Stimson Center Occasional Paper* No. 29, October 1996, 2.

- The placement of all fissile materials under international safeguards; and
- The elimination or conversion to non-nuclear roles of all nuclear delivery vehicles.

Nuclear disarmament to an even higher level still could also include the disposition of *all* weapons-usable fissile materials within a state (not just those removed from dismantled weapons) and the elimination—or severe 'disablement'—of *all* facilities producing such materials.[19] With no weapons-usable fissile materials (i.e. highly enriched uranium (HEU) and/or separated plutonium), and no way to produce them, let alone then fabricate them into a weaponizable form, a state would be incapable of indigenously constructing a nuclear explosive device.

Cumulatively, all of the above steps would make the process of nuclear rearmament costly, difficult, lengthy and quite probably apparent to the wider international community with enough advance warning for action to be taken. The result would thus be an 'end state' of disarmament entailing a substantial degree of irreversibility. Below this level of disarmament, however, the range of other disarmament end states is huge. Different forms of weapons dismantlement and material disposition, and varying ways of addressing (or leaving untouched) various parts of a state's nuclear warhead production complex and civilian nuclear infrastructure, can combine in myriad ways—each with their own implications for irreversibility. We turn first to delivery vehicles.

2.7.2 Delivery vehicles

In theory, as noted above, a state with nuclear warheads but no nuclear-capable delivery vehicles is not really a nuclear-armed state at all as it has no means of delivering those devices to a target. And indeed, as Acton and Perkovich—amongst many others—have noted, because of the difficulties involved in the verification of warheads, 'treaties have to date focused almost exclusively on delivery vehicles and their launchers.'[20] As Fetter wrote in 1996, there are three main reasons for this focus:

> First, delivery vehicles and their launchers are relatively easy to count; silos, submarines, and bombers, unlike warheads, cannot be easily hidden from spy satellites. Second, delivery vehicles are expensive, typically costing up to ten times more to produce and maintain than the nuclear warheads they are designed to carry. Third, nuclear warheads that are mounted on long-range delivery vehicles are considered to have far more military significance than warheads in storage or on short-range delivery systems. Delivery vehicles thus have been the chief currency of nuclear capability, and their elimination would be a natural focus of disarmament efforts.[21]

Moreover, to add a fourth point to Fetter's list, getting access to nuclear warheads will be difficult. In particular, any verification of warhead *dismantlement*, where warheads' inner workings would likely or potentially be exposed, would inevitably run into an array of national security concerns. Dealing with delivery vehicles is a considerably more straightforward undertaking than taking on warheads themselves.

As Fetter has noted, the INF treaty of 1987 and the 1991 START accord (examined in detail in Annex I of this report) established a range of procedures by which delivery vehicles and their launchers could be verifiably eliminated or converted to non-nuclear roles. The treaties also established procedures for ending nuclear-weapon-related activities at production and support facilities. 'Future arms control agreements should limit all nuclear delivery vehicles, regardless of range,' he argued in 1996, and should require the elimination of all delivery vehicles withdrawn from service. 'In some cases, the conversion to non-

19 That is, enrichment and reprocessing facilities in civilian use (since military facilities are already mentioned).

20 Perkovich and Acton, *Abolishing Nuclear Weapons*, 55.

21 Fetter, 'Verifying Nuclear Disarmament', 5.

nuclear missions or peaceful applications might be permitted under strict guidelines and verification,' such as the way in which the START treaty allowed for the conversion of nuclear bombers to conventional roles—i.e. provided that the converted bombers were based separately from nuclear bombers, kept at least 100km from nuclear weapon storage sites, and modified to make them both obviously distinct from nuclear bombers of the same type and unable to carry nuclear armaments.[22]

Moreover, Fetter argues that an agreement to eliminate nuclear weapons 'should be accompanied by a global ban on ballistic missiles' with ranges above 300km. 'Unlike manned aircraft and cruise missiles,' his 1996 paper notes, 'longer-range ballistic missiles have little or no utility for the delivery of conventional munitions.'[23] In the context of nuclear disarmament, cutting out long-range ballistic missiles would be of enormous significance—as such systems form one of the key delivery platforms for nuclear weapons employed, or sought, by nuclear-weapon or aspiring nuclear-weapon states today.

There are, though, at least three practical problems with the theory of nuclear disarmament through delivery system elimination. The first is the often-blurred line between delivery vehicles for nuclear and conventional arms—a 'dual-use' problem, essentially. The second is that the conversion of delivery vehicles to non-nuclear missions could be undone, quite quickly and easily in some cases. And the third revolves around the question of where to draw the line as to what constitutes a potential delivery vehicle for a nuclear warhead or a bomb. As Fetter notes, 'even civilian aircraft or ships could be pressed into service' if necessary.[24]

With those problems in mind, one can make a strong case that while efforts to eliminate nuclear delivery vehicles are not without usefulness, their utility is more as a complementary confidence-building measure to steps directed towards addressing and eliminating warheads directly—ultimately a far stronger guarantee of nuclear disarmament.

2.7.3 Warheads

Having addressed delivery vehicles, it now follows to turn to the other main component of a nuclear weapon—the warhead itself. In general, options for dealing with warheads can be separated into two, by no means mutually exclusive, categories: dismantlement (which leads to range of fissile material disposition options); and pit stuffing (which can be used to disable warheads prior to dismantlement).

Warhead dismantlement

According to the US Department of Energy (DOE), the branch of the US government responsible for the management and stewardship of America's nuclear arsenal, warhead 'dismantlement' refers to the separation of a warhead's high explosives from its fissile material components.[25] (High explosives are used to compress the fissile pit of a warhead and thereby induce a nuclear fission reaction—which, being uncontrolled, unlike in a nuclear reactor, results in the rapid and intensely destructive release of heat, blast and radiation.)

The arrangement of nuclear materials, explosives and various other non-nuclear parts essential to the detonation of a nuclear warhead are generally and collectively referred to as a device's 'physics package'.

22 Ibid., 6–7.

23 Ibid., 7.

24 Ibid., 23.

25 US Department of Energy Office of Arms Control and Nonproliferation, *Transparency and Verification Options: An Initial Analysis of Approaches for Monitoring Warhead Dismantlement*, US DOE, 1997.

To dismantle a nuclear warhead, in line with the DOE definition of dismantlement, the physics package must first be removed from the outer casing of a warhead; only then can its constituent parts be separated.

Specific dismantlement processes vary considerably according to the type of device being dismantled and the way in which the dismantlement chain is organised in different countries. That said, however, all dismantlement processes will necessarily entail a number of common stages.

First, a warhead must be retired from active service and transported, perhaps via an interim storage site, to the facility at which it is to be dismantled. At a dismantlement facility, two main operations are carried out: (i) the extraction of the physics package from the warhead casing; and (ii) the subsequent disassembly of the physics package into its constituent fissile material components, high explosives and other non-nuclear parts. At this stage, the warhead is, by the definition offered above, 'dismantled'. After disassembly of the physics package is complete, its fissile material components may be placed into storage (for a time at least) while high explosives and the various other non-nuclear components of a warhead tend to be more immediately disposed of in ways best suited to their type and properties.[26]

Disposition of fissile materials: After dismantlement, the fate of the fissile material components removed from warheads is a most critical aspect when making determinations as to irreversibility. Together or separately, highly-enriched uranium (HEU) and/or plutonium removed from bombs have the intrinsic potential to be used in new weapons. Although modern nuclear warheads commonly use both materials, the atomic bombs dropped on Japan in 1945 contained either exclusively plutonium, in the case of the 'Fat Man' device, or HEU, in the case of 'Little Boy'. The existence of either material, or both, within a state with nuclear weapons expertise leaves open the possibility that they could be utilised for military purposes at some point in the future—assuming that these materials were present in sufficient 'significant quantities'.

As noted above, once removed from warheads, fissile materials are usually moved to storage facilities to await their fate—which may involve processing into forms that can then be introduced into a civilian fuel cycle, or processing for disposal as waste, or, possibly, for re-use in warheads at some later stage. Obviously, fissile material in storage in weapons-ready form makes for an easy and quick reversal if former weapons material was wanted for new bombs. Thus, if the intention is to change those materials' form and thereby render the dismantlement process less readily reversible, then the sooner they are fed into processing streams for long-term disposition the better.

Disposition options for weapons-usable fissile materials: For highly-enriched uranium, the disposition process is relatively straightforward, as HEU can be 'downblended' with natural, depleted or slightly enriched uranium to produce low-enriched uranium (LEU). Low-enriched uranium is unsuitable for use in nuclear weapons and would require re-enrichment to become weapons-usable.

Excess plutonium poses a more difficult problem, however, as nearly all combinations of plutonium isotopes can potentially be used in nuclear weapons. Thus, blending with other isotopes is unsuitable to render the material unusable for weapons purposes. Plutonium can be mixed with uranium, but chemical separation of the two to recover weapons-usable plutonium is far more easily achievable than enriching uranium to weapons-grade.[27]

One of the most authoritative studies of the existing and potential options for dealing with plutonium is a 1994 NAS report on the *Management and Disposition of Excess Weapons Plutonium*. Therein, the NAS note that the technical options for the long-term disposition of plutonium can be grouped into three categories:

26 See David Cliff, Hassan Elbahtimy and Andreas Persbo, *Verifying Warhead Dismantlement: Past, present, future*, VERTIC Verification Matters No. 9, 3G Printing Ltd, 2010, 16–19.

27 Matthew Bunn, *Securing All Nuclear Materials in Four Years*, Belfer Center for Science and International Affairs/Nuclear Threat Initiative, April 2010, 48.

- *Indefinite storage,* in which plutonium would be stored in directly weapons-usable form for an indefinite period of time, 'with no specific decision concerning whether, when, and how storage would be terminated;'
- *Minimised accessibility,* 'in which physical, chemical, or radiological barriers would be created to reduce the plutonium's accessibility for use in weapons (either by potential proliferators or by the state from whose weapons it came),' by irradiating plutonium in reactors, for example, or by mixing it with radioactive high-level wastes (HLW); and
- *Elimination,* in which plutonium 'would be made essentially completely inaccessible, for example, by burning it in reactors so completely that only a few grams would remain in a truckload of spent fuel, or by launching it into deep space.'[28]

The NAS argued that plutonium disposition should seek to meet a 'spent fuel standard'; that is, that plutonium should be made into a form 'that is at least as inaccessible for weapons use as the much larger and growing stock of plutonium that exists in spent fuel from commercial reactors.'[29]

As Arjun and Annie Makhijani have written, meeting the spent fuel standard does not solve the plutonium problem. Rather, it means 'only that it will be approximately as difficult to re-extract and use plutonium for making weapons as it would be to get it by reprocessing civilian spent fuel.'[30] As the NAS explained, options that leave excess weapons plutonium more accessible than the civilian stock 'would mean that [this excess weapons material] would continue to pose a unique safeguards problem indefinitely.'[31] Conversely, the NAS note, as long as civilian plutonium exists and continues to accumulate, options going beyond the spent fuel standard and seeking to eliminate excess weapons plutonium entirely 'would provide little additional security, *unless the same were done with the much larger amount of civilian plutonium.*'[32]

For those reasons, and after evaluating a broad range of possible disposition options, the 1994 NAS report—and an even lengthier follow-up report in 1995—concluded that the two most plausible disposition options for meeting the spent fuel standard were: (1) to use excess weapons plutonium as fuel in reactors, including, for example, as plutonium-uranium mixed oxide (MOX) fuel in existing light-water reactors; and/or (2) to immobilize it through vitrification (mixing into glass) with radioactive HLW.

A third option that the NAS considered to have some potential also, as far as the spent fuel standard goes, is the disposal of excess weapons plutonium in deep boreholes. As their report noted: 'Plutonium in such boreholes would be extremely inaccessible to potential proliferators, but would be recoverable by the state in control of the borehole site.' Thus, they wrote, 'deep boreholes represent a class of options that go a long way toward eliminating the proliferation risks posed by excess weapons plutonium, but do not go quite as far [as burning in reactors or vitrification] in reducing the potential breakout risks associated with the material's existence.'[33]

Progress on disposition in the US and Russia: As Matthew Bunn noted in April 2010, the US and Russia have so far made 'significant progress' in reducing their stockpiles of excess HEU. By early 2010, for instance, over 380 metric tons of Russian HEU had been destroyed by downblending under the 1993 'HEU Purchase Agreement'. This plan calls for 500 tons of HEU to be destroyed by 2013, when the deal ends. For its part, by the end of fiscal year 2009, the US had downblended nearly 130 tons of excess HEU into LEU.[34]

28 National Academy of Sciences, *Management and Disposition of Excess Weapons Plutonium*, National Academy Press, 1994, 11.

29 Ibid.

30 Arjun Makhijani and Annie Makhijani, *Fissile Materials in a Glass, Darkly*, IEER Press, 1995, 21.

31 National Academy of Sciences, *Management and Disposition of Excess Weapons Plutonium*, 12.

32 National Academy of Sciences, *Management and Disposition of Excess Weapons Plutonium*, 148 (emphasis in original).

33 National Academy of Sciences, *Management and Disposition of Excess Weapons Plutonium*, 198.

34 Bunn *Securing All Nuclear Materials in Four Years*, 49.

Considerably less progress has been made on the plutonium disposition front, however. More than a decade after its signing, the 2000 Plutonium Management and Disposition Agreement (PMDA) between the US and Russia—which called for the verifiable disposition of 34 tons of excess weapons plutonium apiece—has yet to be put into action. In 2010, the two sides agreed to amend the PMDA in order to expand Russia's right to employ fast-neutron reactors in the implementation of the agreement, so efforts to begin implementation may not be delayed for too much longer. But, as Bunn told the US House Subcommittee on Strategic Forces in 2006: 'plutonium disposition can only make a serious contribution to the irreversibility of nuclear arms reductions if it is applied to far more than 34 tons of plutonium on each side.' Even after disposing of 34 tons of the material, he noted, Russia would still have 'well over 100 tons of weapon-grade plutonium remaining, enough to support a stockpile of over 20,000 nuclear weapons,' and the US would still hold over 50 tons, 'enough to support a stockpile of over 10,000 nuclear weapons.'[35]

Thus: 'If irreversible nuclear arms reductions are the goal, then the United States and Russia should reduce their stockpiles of nuclear weapons to low, agreed levels, and reduce their stockpiles of plutonium and HEU to the minimum levels needed to support those agreed warhead stockpiles,' Bunn argued.

New stocks: While reducing existing stocks is undoubtedly important, efforts to halt the production of new stocks are necessary also. Indeed, the problem of fissile material production has been recognised as a key concern since the dawn of the nuclear weapons age. The 1945 Franck Report on the 'Political and Social Problems' of nuclear weapons, delivered to the Truman White House two months before the atomic bombing of Hiroshima and Nagasaki, was the first to advocate controls on fissile materials, proposing either the rationing of uranium ore or 'exact bookkeeping on the fate of each pound of uranium mined.'[36] A year later, the Acheson-Lilienthal report of March 1946 proposed the establishment of an international agency to conduct 'all intrinsically dangerous operations in the nuclear field,' including the production of plutonium and enriched uranium.[37] The Baruch Plan, released just three months after the Acheson-Lilienthal report, proposed a similar international authority that should, among other responsibilities, 'exercise complete managerial control of the production of fissionable materials in dangerous quantities' as well as have ownership and control of 'the product of these plants.'[38]

At present, of the five NPT-recognised nuclear-weapon states, all except China are observing publicly-declared moratoria on the production of fissile material for use in weapons. China is believed to have stopped production as well but has not declared this to be the case. India and Pakistan, both non-parties to the NPT, continue to produce fissile material for use in weapons, while Israel's position is unclear. Uncertainty over the amount and production of weapons-usable fissile material in North Korea remain a matter of serious international concern, particularly since the November 2010 unveiling of a uranium enrichment facility at the North Korean Yongbyon nuclear complex (see Annex II).

Efforts to legally enshrine and extend to other states the current moratoria on fissile material production, through the negotiation of a Fissile Material Cut-off Treaty (FMCT) banning the production of fissile material for weapons, began in the Geneva-based Conference on Disarmament (CD) in 1995—but since then little of real significance has been achieved. Even the parameters of the proposed treaty have yet to be conclusively settled, with a number of CD member states advocating a treaty that goes beyond ending the production of new fissile material and places limits on existing stocks as well. That may be too much to hope form, at least for now. As the report of the International Commission on Nuclear Non-Proliferation and Disarmament (ICNND) argued in 2009: 'At a minimum [the FMCT] should apply to new production (i.e. post the treaty's entry into force) of fissile material, with verification arrangements applied to newly

35 Matthew Bunn, testimony before the US House of Representatives on 'Disposition of Excess Plutonium: Rethinking Security Objectives and Technological Approaches,' 26 July 2006.

36 Franck report on the *Political and Social Problems* of nuclear weapons, 1945.

37 Acheson-Lilienthal *Report on the International Control of Atomic Energy*, 1946, 33–34.

38 Baruch Plan, 14 June 1946, http://www.atomicarchive.com/Docs/Deterrence/BaruchPlan.shtml (accessed on 15 November 2010).

produced fissile material to ensure it is not used for nuclear explosives, and enrichment and reprocessing facilities to ensure that all new production is declared.'[39]

Furthermore, the 'key provisions' of an FMCT should be irreversible, say the ICNND, 'meaning that if a state were to withdraw . . . safeguards agreements would not automatically lapse as a consequence.' And any such treaty 'should also contain provisions for the dismantling of existing fissile material production facilities, somewhat along the lines of the Chemical Weapons Convention.' As the ICNND report notes: 'It is one thing to stop the production of HEU and weapons-grade plutonium by mothballing corresponding facilities which can rapidly resume their activity; it is quite another to destroy the ability to durably prevent uranium enrichment and plutonium extraction.'[40]

'Meanwhile,' as Bunn has observed, 'immense stockpiles of separated plutonium continue to build up in the civilian sector, as plutonium reprocessing outpaces the use of this material as fuel.'[41] What's more, there are currently no major international efforts to end the accumulation of these large civilian stocks. There are, however, several initiatives either in motion or in the pipeline directed toward the so-called 'multilateralisation' of the nuclear fuel cycle (with the intention being to reduce the incentive for states to develop their own uranium enrichment and/or reprocessing facilities), though none of these schemes are yet very far advanced.[42]

Pit stuffing

As an alternative to dismantlement, or as a measure that could be applied to warheads while they were awaiting dismantlement, 'pit-stuffing' exists as a potential option also. As Bunn wrote in 1998, pit-stuffing—originally developed by the Los Alamos National Laboratory to ensure that warheads determined to be unsafe would not explode accidentally—would allow for the disablement of warheads to be undertaken 'rapidly, permanently, and verifiably.'[43] To explain in more detail, Bunn has written that:

> Every modern 'boosted' nuclear weapon has at its core a 'pit'—a hollow sphere of plutonium or highly-enriched uranium, with a tiny tube through it that allows the tritium to be fed into the hollow inside the sphere. If a steel wire is fed in through this small tube until the inside of the pit is 'stuffed' with tangled wire, the pit can no longer be compressed enough by the explosives surrounding it to sustain a nuclear chain reaction—the weapon is physically incapable of going off. [. . .] If the end of the wire is pushed inside the sphere, it cannot be pulled back out—the weapon is permanently disabled. The only way to get the weapon to work again is to dismantle it, remove the pit, cut the pit open and take the wire out, remanufacture the pit, and reassemble the weapon—a long and costly process. (While it might be possible to develop a means to pull the wire back out through the tube, it should also be possible to fray the end of the wire before pushing it in, making it impossible to pull it back out. Additional 'red team' studies should be done to confirm this.)[44]

39 International Commission on Nuclear Non-Proliferation and Disarmament, *Eliminating Nuclear Threats—A Practical Agenda for Global Policymakers*, ICNND, 2009, 108.

40 Ibid., 109.

41 Bunn *Securing All Nuclear Materials in Four Years*, 49.

42 See ICNND, *Eliminating Nuclear Threats*, 132–142.

43 Matthew Bunn, '"Pit-Stuffing": How to Disable Thousands of Warheads and Easily Verify Their Dismantlement', *Federation of American Scientists Public Interest Report* 51, No. 2 (March 1998), 3–5.

44 Ibid. 'Of course, a steel wire is only one of many things that could be used to 'stuff' the pits. Originally, for ensuring the safety of the unsafe weapons, aluminium powder was used—which could be removed by simply shaking the powder back out through the hole. Another approach was to fill the inside of the pit with epoxy—but putting anything organic in with the plutonium leads to chemical reactions that reduce long-term safety, and the bonding of the epoxy and the plutonium made the pit a 'mixed waste' (both radioactive and toxic) under U.S. regulations. The idea of the steel wire was to make it possible to 'stuff' the pits in a way that would have no impact at all on the safety of long-term storage, either of the weapons, or of the pits themselves after the weapons were dismantled. Another possibility would be to stuff the pit with hundreds of tiny 'barbells' whose wide parts are just small enough to fit in through the tube—making it virtually impossible to shake or pull them back out.'

As Bunn noted, the costly and time-consuming process of dismantling nuclear warheads places a limitation on the pace at which nuclear arms reductions can be carried out. 'Pit-stuffing overcomes that problem,' he notes, as 'in principle, it would be possible to disable thousands of nuclear warheads in just a few weeks.' Moreover, once a pit had been stuffed with wire, Bunn has noted, 'this fact can easily be confirmed by a variety of means, such as a gamma-ray image of only, for example, one square inch of the pit.' Verification should thus be possible without revealing 'substantial design information', and would be able to be conducted at 'minimal cost and intrusiveness,' and—because of the speed with which wires could be inserted into pits—in only a handful of inspection visits.[45]

After inspection, and after inspectors had left, the inspected party could then dismantle its unusable warheads in privacy, at its own convenience and according to its own schedule. After dismantlement, inspectors could return and be shown canisters containing the stuffed pits. 'By taking gamma ray images as described above, the inspectors could confirm that the containers contained hollow spheres of plutonium stuffed with tangled wire—a virtually sure sign that these were in fact the pits from the warheads observed before, which had been dismantled in the interim.'[46]

2.7.4 Warhead production complexes

But even with verification, the dismantlement of warheads and disposition of their fissile material components will provide no guarantee of irreversibility unless the capabilities of a state to reproduce or reassemble such devices are addressed also. The network of research, manufacturing and testing facilities that combine in the development of nuclear weapons is generally referred to as the nuclear warhead production complex of a state. As the earlier discussion of 'weaponless deterrence' showed, for as long as a state has such a complex, the option—and the ability—to reverse disarmament and re-deploy warheads will always exist.

In terms of disarmament irreversibility, though, removing certain facilities from the warhead production complex may have a greater impact than others, with this uncertainty resulting from a multitude of variables that need to be taken into account—including the manner in which a particular facility was 'removed' from the complex as a whole.

For instance, given the essential importance of fissile materials to nuclear weapons, one might expect that those facilities involved in the production of HEU and plutonium and their fabrication into pits to be the most important to address of all. But these facilities' elimination, disablement or conversion to other uses would only have a noticeable impact if a state was not already in possession of sufficient quantities of weapons-usable material and/or pits. If it did have sufficient stocks of material, then removing the production facilities for such material would have little impact—but if none of that material was in the form of pits then removing pit fabrication facilities would be a major setback to rearmament capabilities.

It is, furthermore, necessary here to elaborate briefly on the differences—in terms of irreversibility implications—between elimination, disablement and conversion to military uses (or in some cases the absence of differences is more correct). Elimination would obviously present a greater degree of irreversibility than conversion, as it would be more difficult and time-consuming to rebuild facilities from the ground up than it would be to just re-convert facilities to military uses. But for their part, disablement actions may or may not be on a par with elimination, as certain steps in certain facilities would, in effect, 'write-off' that facility (i.e. it would become easier to build anew than to attempt to reverse disablement actions).

45 Ibid.

46 Ibid.

2.7.5 The endurance of knowledge

Leaving aside the tangible aspects of nuclear weapons, this section addresses what has been referred earlier to in this report as the 'endurance of knowledge' problem. That is, the fact that even without actual, assembled nuclear weapons, a state formerly in possession of them would in all likelihood retain for some time the knowledge to rebuild them again. As Acton and Perkovich have written, and following the earlier discussion of 'virtual' nuclear weapons and the ideas of Jonathan Schell:

> Even if reconstitution capabilities were ultimately agreed to be undesirable, it would be inevitable that inequalities between former nuclear-armed states and non-nuclear-weapons states would exist in a nuclear-weapons free world for at least some time after nuclear weapons had been abolished. Dismantling nuclear weapons and destroying their associated infrastructure would not destroy the nuclear know-how that nuclear-armed states currently possess. It would be impossible to conclusively verify that states had not retained some sensitive documentation, just as it is impossible now to verify the extent of the distribution of the nuclear weapons designs sold by the A.Q. Khan network. In any case, much nuclear knowledge is embodied in scientists, engineers and other workers.[47]

How to address the endurance of knowledge is an especially vexing issue. Documents can be destroyed, but as Acton and Perkovich note, the destruction of knowledge embodied in people is impossible, at least not without committing 'gross violations of human rights'. As a result, they write, keeping tabs on the activities of these people would become necessary:

> Many scientists are likely to continue their careers in civilian research establishments, and monitoring their publications would be a useful first step. More intrusive monitoring would provide added reassurance that nuclear-weapons designers and engineers had not resumed their old careers, but this would conflict with privacy rights. What could be done about process workers trained in how to fabricate nuclear weapons and their components? Would their activities need to be monitored, and, if so, how would this be done practically, and without harm to civil liberties? Measures . . . that would make it an international crime for individuals to contribute to the proliferation of nuclear weapons and which would require states in a nuclear-weapons-free world to legally oblige citizens to report evidence of a violation to an international body might help to deter individuals with sensitive expertise from participating in break-out schemes.

Nuclear knowledge would be 'even more difficult to manage' if reconstitution capabilities *were* retained, Acton and Perkovich observe. 'But if and when states reached the point where they decided no longer to employ cadres of nuclear-weapons experts, the problem of lingering nuclear know-how might not last indefinitely.'[48] Rather, it may fade away over time:

> There is evidence to suggest that 'tacit' knowledge—in the words of sociologists Donald MacKenzie and Graham Spinardi, 'knowledge that has not been (and perhaps cannot be) formulated explicitly and, therefore, cannot be effectively stored or transferred entirely by impersonal means'—plays an important role in the manufacture of nuclear weapons . . . MacKenzie and Spinardi give the example of the manufacture of nuclear weapon components. Even in an age of computer controlled machine tools, highly skilled machinists are still needed to manufacture components of sufficient quality for use in nuclear weapons. Artisanal skills such as these can only be learnt 'on the job'; reading an instruction manual will not suffice. Were a generation of machinists to die without training replacements, future generations would, in a sense, have to reinvent their skill.[49]

47 Perkovich and Acton, *Abolishing Nuclear Weapons*, 123.

48 Ibid.

49 Ibid.

If tacit knowledge is relevant to nuclear weapons, Acton and Perkovich note, then the 'transitional phase for nuclear know-how could reasonably be said to last for as long as the final generation of nuclear-weapons designers, engineers and process workers remained alive.' Following this logic, they argue that it might not, as a result, be all that important to verifiably destroy all documentation relating to nuclear weapons design.[50] 'After the transitional phase,' they write, 'former nuclear-armed states would find it as difficult as any other state to build nuclear weapons. Reconstruction would still be possible, but some lost tacit knowledge would need to be rediscovered.'[51]

2.8 Achieving irreversibility

From all that has been said above, one can plausibly make the case that, if all nuclear warheads in a state were dismantled, the irreversibility of that disarmament (following the non-dictionary meaning of irreversibility outlined earlier) would depend—above all—on the following:

- The amount of weapons-usable fissile material in the state in the form of intact (and unstuffed) pits; and, thus, able to be directly used—or re-used, as the case may be—in warheads;
- The amount of weapons-usable fissile material in the state in forms not immediately able to be implanted in weapons (i.e. in non-pit form, whether that material is safeguarded or not);
- The capabilities of the state to produce weapons-usable fissile material and, separately, to fabricate that material into pit forms that can be implanted into warheads;
- The existence or absence of warhead assembly facilities within the state, where pits and the various non-nuclear components of a warhead would be combined; and
- The availability of delivery systems that could deliver warheads to a target in a reliable fashion.

Obviously, knowledge and expertise are critically important factors also. Knowledge and expertise, for obvious reasons noted above, provide crucial linkages between the necessary components of a warhead and a functional device.

For their part, the deterrent effect of international safeguards and other verification and monitoring measures will likely play a role in changing states' calculations with regard to making reversals. If caught early enough, moves toward rearmament could be met with a concerted and robust response, perhaps by just one state or a few, but perhaps also on a more inclusive, broader multilateral basis.

The various combinations of the above variables are almost endless, however, as are the consequent implications for irreversibility. Furthermore, not all of the factors listed above are necessarily important for every state. For example, a state with a lot of intact pits in storage—perhaps as they await processing for long-term disposition—would not have the same need for pit fabrication facilities as a state with no pits but a large stockpile of weapons-usable fissile material. Or any need, in fact, if at the point of deciding to rearm it judged itself to still be in possession of enough pits to meet its defence and security needs. By the same token, a state with a large stockpile of weapons-usable fissile material would not necessarily need the capabilities to produce any more.

Where a state is lacking in some areas that it *does* require for rearmament, however, the absence of some materials and/or facilities will have a greater bearing on irreversibility than the absence of others. For

50 Ibid. Acton and Perkovich also note that the transitional period could theoretically be shortened if nuclear-armed states had wound down their weapons programmes some years before disarmament 'by not making new appointments, and retaining only a skeleton staff sufficient to ensure the safety of the few remaining weapons.'

51 Ibid.

instance, rearmament in a state with intact pits, reliable delivery systems, and technical know-how but a need to construct a warhead assembly facility—which, for obvious reasons, is critically important—will likely be a simpler process than rearmament in a state with assembly facilities, delivery systems and know-how but no weapons-usable fissile materials. It is almost a truism to say that the acquisition of fissile materials is the hardest part of nuclear bomb-making. If a state has no pit fabrication facilities either, in addition to having no weapons-usable fissile materials, then rearmament will be that much more difficult still.

The passage of time factor is important as well. Over years and decades and generations, the 'artisanal skills' (as Acton and Perkovich put it) necessary at certain points of the warhead manufacturing process will erode away if not passed on to new cadres of machinists. As the IPFM have noted, the capabilities for warhead production in general are likely to atrophy if warheads are not being built and no intact ones are left to maintain.[52]

While neither a decline in essential human skills or of the production complex more generally—both inevitable consequences of disarmament—would be themselves irreversible, their potential impact on the rearmament capabilities of a state should not go unmentioned.

Given the vast array of possible combinations of variables, then, it is difficult to point to any one or two parts of a warhead production complex where elimination (or disablement to the effect of elimination) would have the greatest implications for irreversibility. Warhead assembly facilities are an obvious candidate, as it would be here that fissile materials and the various non-nuclear components of a warhead would be fitted together. Without an assembly facility, a state might have the right fissile materials in the right form and all the multitude of non-nuclear parts a warhead needs, but nowhere suitable to put them all together. In terms of rearmament time and difficulty, though, as noted above, constructing an assembly facility would likely be easier—and less conspicuous—than the construction of facilities for the production of fissile materials for weapons (or equivalent facilities for civilian use), if they were removed instead.

Eliminating facilities for the production of weapons-usable HEU and/or plutonium—regardless of whether those facilities were in military or civilian use—would only have a significant impact, however, if a state did not already have a sufficient stockpile of such materials. Similarly, eliminating pit fabrication plants in a state with lots of intact pits would have nothing like the impact on irreversibility as it would in a state with no intact pits whatsoever. An optimal scenario might be in a disarmed state with only small quantities of weapons-usable fissile materials, or none (and nothing in pit form), where getting rid of any enrichment or reprocessing facilities that could produce such material would deal a significant blow to any rearmament prospects.

All of which points toward a conclusion that, *ultimately, perhaps the best way to ensure irreversibility after disarmament (i.e. after all nuclear warheads have been dismantled) is:*

- *To destroy all fissile materials removed from dismantled weapons;*
- *To reduce to very low levels—or ideally eliminate—any and all stockpiles of HEU and plutonium; and*
- *To eliminate any facilities within former nuclear-armed states involved in enrichment and/or reprocessing (whether for civilian purposes or not).*

A state with low-enriched uranium would be unable to produce weapons-usable HEU without any means of enrichment, and without reprocessing plants would be similarly unable to separate weaponizable plutonium from spent reactor fuel.

52 IPFM, *Global Fissile Material Report 2009*, 25.

In such a scenario, everything else takes on a rather more incidental, complementary, hue. Without weapons-usable fissile materials, there is nothing for a pit fabrication facility to work with, nothing for a warhead assembly facility to implant in a warhead and coat in explosives, and nothing—most crucially of all—to create a nuclear explosion.

2.8.1 Degrees of irreversibility

Overall, in as much as a model of the disarmament irreversibility continuum can be arrived at, and applied to theoretical examples (see next chapter), it is possible to identify at least five general degrees of progressively-enhanced post-disarmament irreversibility.[53] Given the importance of fissile materials, it is with regard to these that the focus of this model—at each of the three five stages—lies. That said, however, alongside measures addressing fissile materials and fissile material production, the more facilities involved in the manufacture and assembly of warheads that are removed, and the less nuclear-capable delivery vehicles there are, the more irreversible the situation will be (albeit taking into account that the removal of certain facilities will have greater impact in some states than others).

The first, and lowest, level of irreversibility would entail the dismantlement of warheads—i.e. the removal of fissile materials from the physics package of all such devices—and the ceasing of production of all fissile material for weapons uses. Dismantlement would meet the minimum level of disarmament outlined earlier, and notwithstanding the possibility of hedging, the continued military production of fissile materials to be used in weapons would be unnecessary in a state giving up its nuclear arms.

A slightly higher level of irreversibility would entail all of these measures plus the destruction of all warhead pits. Levels one and two, therefore, deal with the warhead aspect of a state's nuclear arsenal. For their part, levels three, four and five (outlined below) also entail measures to control and address the ability of a state to produce *new* warheads from new fissile material.

Thus, level three would entail not just the dismantlement of warheads and destruction of their pits, but also a *verifiable* commitment by the state in question to use nuclear technology for solely peaceful uses. At this level of irreversibility, there would be monitoring by the IAEA of all nuclear facilities—especially enrichment and reprocessing plants—as well as the monitoring of all stocks of HEU and plutonium. Those stocks would be progressively eliminated by conversion to non-weapons-usable forms and, possibly, reintegration back into a civilian fuel cycle.

Level four would modify the above steps only in as much as enrichment and reprocessing facilities would be eliminated so as to ensure that the state in question had no indigenous means of rebuilding its HEU and plutonium stocks. To reach this fourth level of irreversibility, then, a state would need to: dismantle all its warheads; stop the military production of fissile materials; destroy all warhead pits; dispose of all HEU and separated plutonium; and—perhaps most crucially of all—renounce *all* facilities (i.e. those in both military and civilian uses) involved in the enrichment and/or reprocessing of uranium.

The fifth and highest level of irreversibility would go further still, in as much as this level would entail a state's complete abandonment of nuclear infrastructure—that is, the removal of all nuclear facilities, reactors and all. Short of this 'green-field' extreme, though, the destruction of all weapons-usable fissile materials (including those extracted from a state's dismantled warheads) and removal of the capabilities to produce more would likely ensure that disarmament could not be easily, or particularly subtly, reversed.

53 Not all of the steps outlined in this model need necessarily follow sequentially (the Level Four elimination of enrichment and reprocessing facilities, for example, could theoretically be taken in addition to the steps outlined in Level One, or even before—i.e. while the state in question was still disarming). Some steps, however, *will* only be able to be taken once other actions are taken first (pit destruction will require at least some warheads to be dismantled and their pits extracted first, for instance). This sequential model has been developed for ease of analysis and to enable a manageable—but still useful—level of applicability to the various hypothetical states outlined in Chapter 3.

A table showing possible degrees of disarmament irreversibility

Level One	Dismantlement of warheads (i.e. separation of fissile materials from 'physics package'; Ceasing production of all fissile material for weapons uses
Level Two	Dismantlement of warheads Ceasing production of all fissile material for weapons uses; *Plus:* Destruction of warhead pits
Level Three	Dismantlement of warheads Ceasing production of all fissile material for weapons uses; Destruction of warhead pits; *Plus:* Destruction of all stocks of HEU and plutonium (placed under monitoring while awaiting destruction); and Monitoring of all nuclear facilities (as in NPT non-nuclear-weapon states), especially those involved in enrichment and reprocessing.
Level Four	Dismantlement of warheads Ceasing production of all fissile material for weapons uses; Destruction of warhead pits; Destruction of all stocks of HEU and plutonium (under monitoring while awaiting destruction); *Plus:* Elimination of enrichment and reprocessing facilities (i.e. cessation of production of all potentially weapons-usable fissile materials); Monitoring of all nuclear facilities (as in NPT non-nuclear-weapon states)
Level Five	Dismantlement of warheads Ceasing production of all fissile material for weapons uses; Destruction of warhead pits; Destruction of all stocks of HEU and plutonium (placed under monitoring while awaiting destruction); *Plus:* *Elimination of all nuclear facilities*, including reactors—not just those facilities involved in enrichment and reprocessing

3. Applications

In this section of the report, we are seeking to apply the theory of irreversibility identified in the first chapter of this report to a range of hypothetical countries pursuing nuclear disarmament. The purpose of this analysis is to explore options for various states of irreversibility that are potentially applicable to different disarming countries and their fuel cycles.

The three hypothetical scenarios constructed for this chapter were chosen as representative of various categories of nuclear-armed states that might be encountered in the real world. Needless to say, the range of possible variations within these categories can be vast. As this report has noted elsewhere, irreversibility options are complicated by the possibility of a vast range of disarmament 'end states'—an inevitable consequence of the complexity of fuel cycle arrangements in different countries around the world. To investigate each possible fuel cycle and warhead production complex, and every possible combination of disarmament measures and steps, would be near impossible. Thus, in developing the scenarios for this chapter, the aim was to invent hypothetical states and fuel cycles that were broad enough to allow for a more comprehensive discussion of the various options for disarmament available.

3.1 Country A: the nuclear-weapon state

This country is a nuclear-weapon state with an advanced fuel cycle, large stocks of fissile material and a large number of nuclear warheads both operationally deployed and in storage. It is a party to the NPT (as a recognised nuclear-weapon state) and the IAEA Statute. It is now disarming, unilaterally. This section of the report looks at how this disarmament might be achieved to varying degrees of irreversibility, in accordance with the five levels of irreversibility outlined in the Analytical Overview to this report.

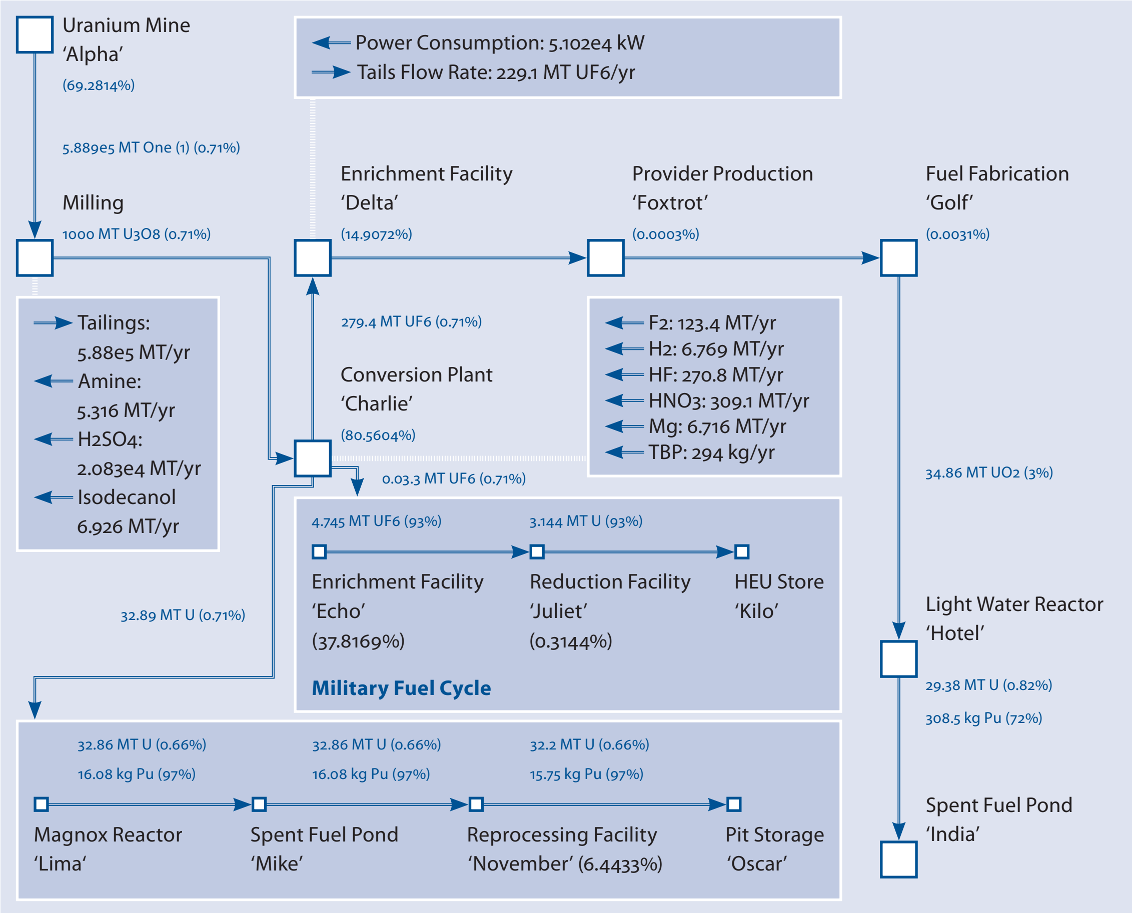
3.1.1 Nuclear activities in Country A

Country A has been producing materials for use in nuclear weapons for 20 years. It has one uranium mine, with ample reserves of uranium ore. After ore extraction, this ore is shipped to a mill, which has the capacity to produce 1,000 tonnes of yellowcake uranium per year. About 4,000 drums of yellowcake are produced by the plant every year.

The yellowcake is then shipped to a conversion facility. This facility also has the capacity to process 1,000 tonnes of uranium per year. At present, it is producing uranium hexafluoride gas for two different enrichment plants (one in civilian use and one for military uses), and some 32.89 tonnes of natural uranium metal for use in the country's sole Magnox reactor.

The civilian enrichment plant operates using gas centrifuges and produces some 50.35 tonnes of three per cent enriched uranium hexafluoride gas per year. This material is then shipped to a fuel manufacturing plant where it is converted into uranium dioxide fuel assemblies, which are then loaded into a light-water reactor. This reactor discharges some 29.38 tonnes of 0.83 per cent enriched uranium metal per year. In

Diagram showing the fuel cycles and material flows in Country A



addition, it produces 308.5kg of reactor-grade plutonium (containing 73 per cent Pu239). No spent fuel from the light-water reactor is being reprocessed.

The military enrichment plant also uses gas centrifuges. It receives 863.3 tonnes of gas per year from the conversion facility. From that gas, it produces 4.745 tonnes of HEU—which is then shipped to a military conversion facility, where the fluoride gas is removed and the uranium worked into metal shapes. That metal, amounting to 3,144kg per year, is then kept in a military storage facility before being sent for weaponisation.

The Magnox reactor loads 32.89 tonnes of natural uranium metal per year. This is then unloaded on a continuous basis into a spent fuel cooling pond. After one year of cooling, the spent fuel is sent to a reprocessing facility where, using the PUREX process, 15.75kg of weapons-grade plutonium (97 per cent Pu239) is separated per year. This plutonium is sent to a military storage facility, before being shipped off for weaponisation.

After 20 years, Country A has amassed over 60,000kg of weapons-usable U235; 91kg of weaponizable Pu239; 108 uranium-based nuclear explosive devices; and 21 plutonium devices. The country's total arsenal thus stands at 129 devices. Country A has deployed those devices as follows:

- 60 uranium-type devices deployed on 20 ICBMs (four warheads per missile). These missiles are grouped into four missile regiments (i.e. four silo complexes holding five missiles each).
- 36 uranium-type devices deployed on 36 SLBMs (one warhead per missile), which are deployed on three submarines.
- 12 uranium-type devices are regularly off-service for maintenance and safety checks.
- 17 plutonium-type devices are in the form of gravity bombs, carried by strike fighter aircraft.
- 4 plutonium-type weapons are regularly off-service for maintenance and safety checks.

Country A is a member of a defence pact that requires it to base some of its gravity bombs abroad from time to time. Regarding indigenous levels of expertise, Country A is a Western state with a highly skilled and educated workforce and strong industrial and scientific sectors. It has no suspected ties to nuclear black market procurement networks.

3.1.2 Applications of irreversibility

The case of Country A illustrates a fairly rudimentary nuclear-weapon state. Like all nuclear-weapon states in the world today, it has both a military and civilian nuclear fuel cycle. In this case, the fuel cycles are not entirely disconnected. They both depend on Country A's uranium conversion facility. In addition, since it is employing centrifuge technology for both military and civilian purposes, it can be assumed that Country A has mastered enrichment technology.

The various levels of irreversible disarmament, as outlined earlier in this report and here applied to Country A, can be summarized as follows.

Level 1	Dismantlement of warheads; Ceasing production of all fissile material for weapons-uses.	All 129 warheads in Country A's possession would be dismantled (i.e. separation of fissile material and high explosives in physics packages); Magnox reactor would be shut down, but maintained ready for use, or converted to civilian uses; Production at military enrichment facility would be stopped, or the facility would be converted to civilian uses.
Level 2	Dismantlement of warheads; Ceasing production of all FM for weapons-uses; *Plus,* Destruction of warhead pits.	As above, *plus,* All 129 warhead pits destroyed outright or re-integrated into Country A's civilian fuel cycle.
Level 3	Dismantlement of warheads; Ceasing production of all FM for weapons-uses; Destruction of warhead pits; *Plus,* Destruction of all stocks of HEU and plutonium (placed under monitoring while awaiting destruction); Monitoring of all nuclear facilities (as in NPT non-nuclear-weapon states), especially those involved in enrichment and reprocessing.	As above, *plus,* All stockpiles of HEU and plutonium held by Country A would be destroyed, either by down-blending (in the case of HEU) or through burning in reactors/vitrification (in the case of plutonium); IAEA safeguards would be applied to Country A's mine, conversion facility, LWR, civilian enrichment facility and reprocessing plant; If converted to civilian uses, IAEA safeguards would also be applied to Country A's Magnox reactor and military enrichment facility (if not, then verification measures would be applied to ensure their continued shutdown)
Level 4	Dismantlement of warheads; Ceasing production of all FM for weapons-uses; Destruction of warhead pits; Destruction of all stocks of HEU and plutonium (placed under monitoring while awaiting destruction); *Plus,* Elimination of enrichment and reprocessing facilities, (other facilities remain under monitoring).	As above, *plus,* Country A's civilian and military enrichment facilities would be decommissioned; Country A's reprocessing plant would also be decommissioned also; Country A's LWR would seek alternative, perhaps multilateral, arrangements for the provision of sufficient fuel.
Level 5	Dismantlement of warheads; Ceasing production of all FM for weapons-uses; Destruction of warhead pits; Destruction of all stocks of HEU and plutonium (placed under monitoring while awaiting destruction); *Plus,* Elimination of *all* nuclear facilities, including reactors – not just those facilities involved in enrichment and reprocessing.	All 129 warheads dismantled; All stocks of HEU and plutonium destroyed; Country A's LWR would be shut down, as would its Magnox reactor, conversion, enrichment and reprocessing facilities;

It will likely not have gone unnoticed that this model deals only with the fissile material component of Country A's nuclear bomb-making programme, leaving weaponisation facilities largely unmentioned. As noted earlier to this report, with the acquisition of fissile materials representing the biggest obstacle to nuclear weapons development, the authors would argue that it is more suitable that this model of disarmament irreversibility focus on the fissile material side of nuclear weaponisation, not warhead assembly. However, Country A *could* disable or otherwise eliminate critical parts of its warhead production complex, especially pit fabrication and weapons assembly plants, which would complicate rearmament even further. And if, for instance, a pit fabrication facility was eliminated in tandem with Level 2 (destruction of pits), then that facility—or one similar—would have to be rebuilt before pits could be remade, thus adding a further layer of irreversibility to that part of the model. For reasons mentioned also in the Analytical Overview chapter of this report, this model also leaves nuclear delivery vehicles to one side.

The following section explores each of these five levels in greater depth, including also possible variations and complementary steps that could be taken *within* each level to enhance irreversibility. The levels are designed in such as way to make reversibility steadily more difficult, costly and time-consuming—in line with the understanding of disarmament irreversibility reached earlier in this report.

Level 1

To reach Level 1, Country A would first need to withdraw its nuclear warheads from active deployment, regardless of where they are based (at home or abroad). Once the decision to retire warheads from service was taken, those warheads would first be removed from their delivery systems—i.e. de-mated from missiles and/or taken out of aircraft bomb bays—and moved into storage. At this stage, keeping in mind that dismantlement has yet to occur, the level of reversibility would be extremely high, especially if storage sites were located geographically close to delivery systems and launchers (on the same military base, for instance). That said, even if warheads awaiting dismantlement were kept far away from nuclear delivery systems when a decision to reverse de-mating was taken, the time needed for missiles and bombers to be rearmed would likely only be in the order of hours and days, not weeks or months or longer.

Dismantlement

To start dismantlement, warheads need to be moved to a dismantlement facility, which in many cases function both as an assembly/disassembly facility. After arriving at the dismantlement facility, safety checks will likely be carried out to ensure the integrity of the warhead after its removal from its delivery system. Dismantling one warhead may take a number of weeks to complete but the exact time and procedures needed to dismantle one warhead differ depending on the type and age of the warhead in question.

Once facility staff are ready to dismantle a warhead, one would be moved out of storage and into a dismantlement bay. There, the warhead will be removed from its shipping container and the physics package containing the warhead's fissile material components and high explosives extracted from the warhead's casing.

The next most important step in the dismantlement process would be the disassembly of the physics package itself. At this stage, the nuclear, non-nuclear and high explosive components of the package are separated out. According to the US Department of Energy definition, once this stage is reached, dismantlement can be said to be complete.[54]

54 As noted earlier in this report, according to a 1997 US Department of Energy study, warhead 'dismantlement' refers essentially to the separation of a device's high explosives from its fissile material components.

The dismantlement of all nuclear warheads in Country A would meet the disarmament minimum outlined by Steve Fetter and followed throughout this report. At this stage, the disarmament of Country A could be said to be complete—but still highly reversible. If fissile materials from warheads were kept in pit form, they would remain readily re-usable in nuclear weapons if Country A chose to reconstitute its nuclear arsenal, or part of it, at some point in the future.

Military fuel cycle measures

In addition to the dismantlement measures suggested above, and to achieve a credible first level of irreversibility, Country A will likely have to also take measures to freeze its military fuel cycle. The aim of such measures is to cap Country A's stockpiles of weapons-usable fissile material through stopping the production of new material. This would mean that as dismantlement of weapons stockpile takes place, fissile material cut off measures should be in place.

In terms of actual measures, this would entail addressing, at a minimum, two critical facilities in Country A's military fuel cycle. These are its military enrichment facility and its reprocessing facility. At a maximum, this could also include measures addressing all facilities involved in its uranium-based as well as its plutonium-based military fuel cycles. While the minimum level suggested would ensure that crucial nodes of the military cycle are targeted, the maximum level could provide greater assurances that even flows to such facilities are taken into account.

The range of measures that can be applied to the military fuel cycle can be diverse. Such measures can include: freezing and shutting down such facilities (i.e. Country A's military enrichment and reprocessing at a minimum, and possibly its Magnox reactor for greater assurance), or effecting their removal from the military fuel cycle by converting them to peaceful uses. To achieve the latter, a clear separation of the civilian and military fuel cycles would be necessary. Applying material accountancy at converted facilities would provide greater confidence that no diversion back into a military fuel cycle is taking place.

Problematically, HEU has civilian applications and separated plutonium is a by-product of civilian reprocessing. As a result, Country A might declare itself to be giving up the production of fissile material for weapons purposes, *while still carrying out the same procedures for use in, or in connection with, civilian applications*. In Country A's case, enrichment of UF6 at its military enrichment facility could be stopped short of weapons-grade and directed into the civilian fuel cycle, and the reprocessing plant could be switched to civilian purposes (to recycle fuel from its LWR, or Magnox, if the latter was switched to civilian uses also), with separated plutonium produced at the plant simply not sent for weaponisation.

Even a shut-down of Country A's military enrichment and reprocessing facilities entails possibilities for reversal, however, as both facilities could be started up again relatively quickly—especially if no medium-to-long-term disablement actions were taken there.

Moreover, even if Country A's military enrichment facility was shut down as part of efforts to stop its military fuel cycle, no action would necessarily have been taken at the civilian enrichment facility, which in the future could potentially be used to produce high-enriched uranium for use in weapons. Such a conversion would also not likely take long, as the process of enrichment to produce LEU and enrichment to produce HEU is the same, but run for longer. The process of uranium enrichment to a high purity level is also aided by the significantly easier and less energy-intensive work needed to enrich the material at progressively higher levels of purity. Once at 20 per cent purity, for instance, most of the difficult work of enrichment has already been done.

In the case of Country A, the Magnox reactor was strictly geared for production of spent fuel which was further processed to produce weapons-grade plutonium. As such, it had no connection either to Country A's civilian fuel cycle or to its national power grid. Therefore, Level 1 for Country A can include the shutdown (perhaps with disablement), or the conversion of its Magnox reactor. Of course, converting the Magnox to civil uses and shutting down the reprocessing plant would provide a greater level of assurance of disarmament irreversibility because plutonium in the spent fuel from the Magnox could not then be separated out without first bringing the reprocessing facility back online—which, if sufficiently robust disablement actions were taken, could take some considerable time. Moreover, it might be beneficial to put Country A's spent fuel pond under monitoring to ensure that any spent fuel in storage is not diverted elsewhere.

Extra measures

To enhance confidence in both the dismantlement of its warheads and capping its military fuel cycle, Country A might consider allowing inspectors from another country (or other countries) to conduct verification of these activities. The myriad array of issues associated with dismantlement verification go beyond the scope of this paper;[55] suffice to say, however, that verifying warhead dismantlement is a highly complex undertaking to plan and execute—one that is fraught with potential safety and proliferation dangers, but one that has, nonetheless, the potential to bolster confidence in disarmament commitments substantially.

In the cases where military fuel cycle facilities are shut down, it might also be beneficial to include various disablement measures. Such measures would aim at increasing the time needed for Country A to reverse its shut-down and bring its facilities back online.

Disablement measures can take a wide variety of different forms, and can be implemented independently or in combination with one or more other disablement actions. One could argue that even the non-maintenance of shut-down facilities (other than to prevent leakages of nuclear material, or other serious health and safety issues) constitutes a disablement action. Non-maintenance of the DPRK's Yongbyon fuel fabrication facility during the 'freeze' of 1994–2002, for instance, saw that facility fall into a state of considerable disrepair.

On the other hand, shutting down facilities but keeping them maintained would likely allow them to be put into operation soon after a decision to do so was taken. In Country A, even within Level 1, a considerably higher degree of irreversibility would be reached if facilities that were shut down were not subsequently maintained. If Country A decided to shut down its Magnox reactor and reprocessing plant (effectively closing its plutonium route to a bomb) but kept both facilities maintained and ready to start production and plutonium separation from spent fuel at short notice, then the act of shutting down the facilities could be quickly and easily reversed by a simple political decision to do so.

But, as the case of North Korea shows, there are many disablement actions beyond non-maintenance that can be taken at different nuclear facilities to complicate their restart and lengthen the time that reversal would take. Indeed, some disablement actions, or combinations of them, have a cumulative effect similar to the outright elimination of that facility as it becomes more economical to rebuild from scratch than to try to 're-enable' what is already there. Recovering a facility where key rooms have been entirely filled in with concrete, for example, may be more problematic, costly and lengthy than building that facility again from the ground up.

Level 2

Level 2 goes a step beyond the dismantlement of warheads by requiring the destruction/conversion of the fissile pits contained within them. The same constraints on the former military fuel cycle that applied at Level 1 would be upheld.

55 These issues were explored in depth in VERTIC's report on *'Verifying Warhead Dismantlement: Past, present, future'*, released in September 2010.

Dismantlement with pit destruction

At Level 2, then, the principal change—or extension—is that all pits removed from Country A's 129 warheads would be destroyed. The uranium from uranium-based pits could be destroyed by downblending into low-enriched uranium while, in keeping with the NAS's 'spent fuel standard', the plutonium from its plutonium-based pits could be disposed of either through burning in reactors or vitrification with other radioactive substances.

With all its warheads dismantled and all pits destroyed, the level of irreversibility would be significantly increased, since Country A would have to go through the process of re-manufacturing pits for use in warheads before warheads could be re-assembled.

Extra measures—the potential benefits of pit stuffing

It is worth noting at this stage, however, that disposition of excess fissile materials from weapons is not a quick process—and particularly so if a large volume of materials is involved. Thus the concept of pit stuffing becomes relevant. Pit-stuffing can in theory be done quickly and relatively easily, and would render pits unsuitable for use in nuclear weapons unless the wire used to stuff the pit was removed (which, as Matthew Bunn has argued, would not be an easy task).

Given the time needed to destroy all pits, the potential benefit of applying pit stuffing to those in storage is clear. If all warheads were dismantled and all pits scheduled to be destroyed (but unstuffed) when some unforeseen crisis drove Country A to decide to rebuild a small nuclear arsenal, then those pits still awaiting destruction could be immediately moved to a warhead assembly facility and re-inserted into warheads. But if all warhead pits were stuffed when the same crisis erupted, Country A would have to either find a means of extracting the wire from the pits or re-make the pits altogether.

The other main benefit of pit-stuffing is its verifiability, and since stuffing can be undertaken quickly, inspectors verifying the process would be able to do so in relatively short space of time, thereby minimising the disruption to site operations and the risk that inspectors might learn information of value during inspection visits.

Level 3

At the third level outlined above, Country A would not only dismantle its warheads, stop producing fissile material for military purposes and destroy all warhead pits, but also destroy all stocks of HEU and plutonium in its possession, perhaps by, again, downblending (in the case of uranium), and burning and vitrification (in the case of plutonium). At Level 3, Country A would also submit its nuclear facilities—all of which should now be either shut down or in civilian uses—to IAEA safeguards. This would involve a Comprehensive Safeguards Agreement (or some equivalent arrangement) at a minimum, or, ideally a Comprehensive Safeguards Agreement plus IAEA Additional Protocol (or equivalent).

Destruction of stocks

At Level 3, the destruction of all stocks of HEU and plutonium would enhance irreversibility further, because Country A would have to re-enrich enough uranium to a sufficient level of purity and/or separate enough plutonium before a pit fabrication facility could even begin to manufacture the fissile pits for a warhead. Level 3 thus adds another layer of complexity and time to the rearmament process. And verification measures introduced at this stage are likely to provide an added degree of assurance against rearmament, as any move to divert nuclear material to a bomb programme would likely be spotted by the monitoring (whether remote or in person) of Country A's fuel cycle by the IAEA or others. Though verification cannot stop a certain course of action being taken, it can act as a deterrent against rearmament if backed up by suitable—and well-communicated—enforcement mechanisms.

Introduction of safeguards

By requiring all nuclear material and facilities to be placed under IAEA safeguards, Level 3 effectively brings a country on a par with an NPT non-nuclear-weapon state. In Country A's case, if safeguards were implemented fully then they would certainly apply to its mine, mill, conversion facility, fuel fabrication facility, LWR, civilian enrichment facility and spent fuel storage sites. If converted to civilian uses, IAEA safeguards would also cover the Magnox reactor, reprocessing plant and former military enrichment facility. If these had instead been shut down, then other verification measures could be taken to provide assurance on their continued disablement.

Level 4

Level 4 of the disarmament irreversibility model, as applied to Country A, would see both enrichment facilities and the reprocessing facility eliminated—either outright or through disablement actions so severe that it would take longer and cost more to re-enable them than it would to build them again from scratch.

Elimination of sensitive nuclear technologies

The purpose of Level 4 is the elimination of all enrichment and reprocessing facilities within a country, which, if all pits and stocks of weapons-usable fissile materials were gone, would enhance irreversibility substantially. If a state was to disarm to this fourth level of irreversibility, then to rearm it would first need to rebuild one or both of the so-called sensitive nuclear technologies before it could even begin to rebuild HEU and/or plutonium stocks.

The removal of enrichment facilities in Country A would require alternative fuel supply arrangements to be sought for its LWR. And herein lies one of the principal issues involved in any recommendation that sensitive nuclear technologies should be abandoned. Until adequate multilateral supply assurances are more fully developed, states are highly unlikely to give up their right—a right enshrined in the NPT—to develop and use enrichment and reprocessing facilities under their own national control.

Level 5

The fifth level of this model of disarmament irreversibility could also be called the 'green field' option—that is the complete abandonment of all nuclear technology and facilities and, effectively the restoring of nuclear sites to the 'green fields', so to speak, on which they were built. This level of denuclearisation might well be unrealistic, especially in a time of growing concern over 'clean' energy options, but it does nonetheless represent perhaps the most extreme level of nuclear disarmament irreversibility.

With a state of complete denuclearisation, nuclear rearmament would require Country A to restart mining and milling operations, rebuild conversion plants, reactors, fuel storage sites, enrichment facilities and/or reprocessing plants and all the myriad supporting buildings, roads and infrastructure needed to manage a nuclear power and/or weapons programme. The cost and time required to do so would be huge, and with the passage of time, a state may lose much of the skills and human knowledge needed to run such a programme effectively—thus the training/re-training of new personnel would be needed (although who would do this is hard to say), driving up costs and time still further.

In any case, the level of irreversibility—considered in terms of costs, time and difficulty—at disarmament to Level 5 would be extremely high. At a minimum, moving from a state of complete denuclearisation to one of nuclear weapons possession would take several years, and possibly over a decade. For instance, if one is to be guided by the length of time taken for those nuclear-weapon states whose nuclear weapons were developed in dedicated military programmes, such efforts can be completed within a decade. This, of course, assumes a strong level of pre-existing industrial and scientific capabilities, which Country A is assumed to have. Thus, at the 'green field' level, it could be assumed that it would likely not take Country A more than a decade to reverse this level of disarmament.

3.2 Country B: the de facto nuclear-weapon state

This country is a smaller nuclear-weapon state, but one with a relatively advanced nuclear fuel cycle. It holds stocks of fissile materials, and a smaller number of nuclear warheads and gravity bombs than Country A, both operationally deployed and in storage. Unlike Country A, Country B is not a party to the NPT. But like Country A, it is a member of the IAEA and is also now disarming—again unilaterally.

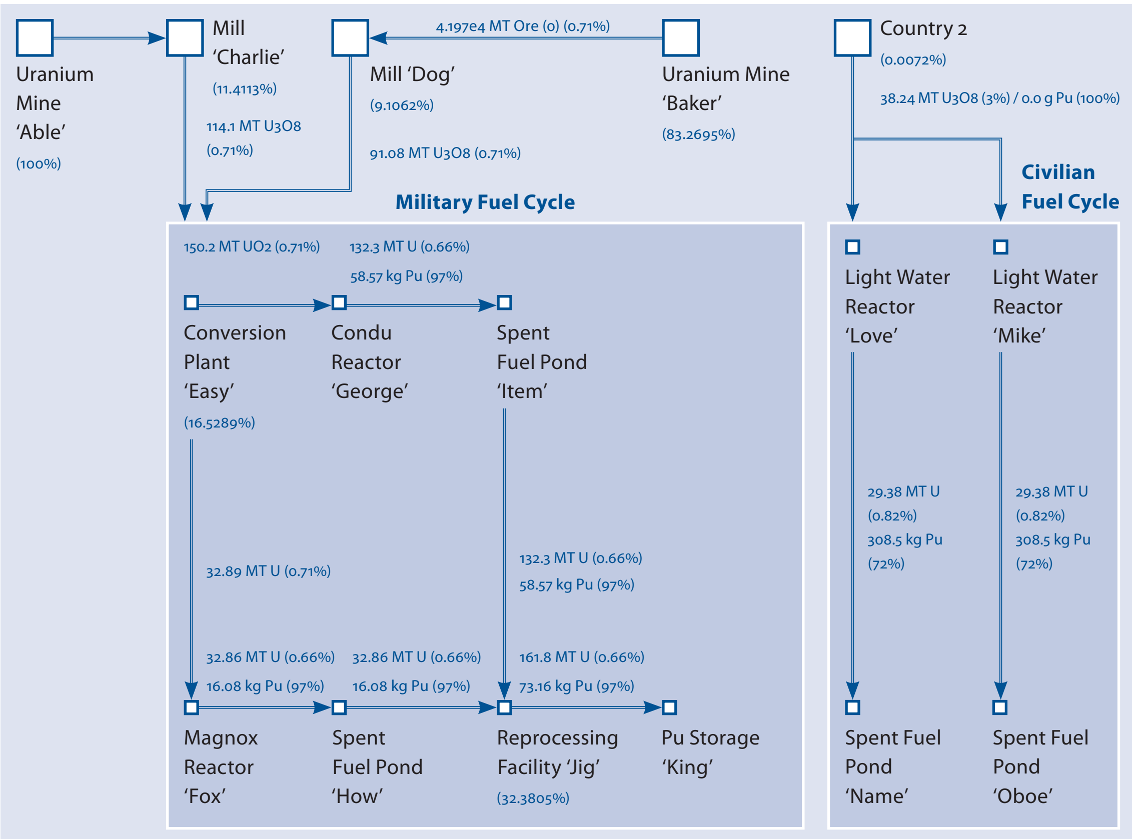
3.2.1 Nuclear activities in Country B

Country B has two uranium mines that supply uranium ore to two uranium mills. All yellowcake from those mills is shipped to Country B's sole conversion facility, where it is converted into uranium metal.

From the conversion facility, 32.89 tonnes of uranium metal is shipped to a Magnox reactor. This fuel is irradiated on a low burn-up and then discharged into a spent fuel cooling pond, where it is left to cool for around a year before being sent to a reprocessing facility. The reprocessing facility has been in operation for 20 years.

Separately, 150.2 tonnes of uranium dioxide fuel is shipped to a 13-year-old CANDU reactor. This fuel is similarly irradiated on a low burn-up before being sent to Country B's reprocessing facility via a cooling

A diagram showing the fuel cycles and material flows in Country B



pond. The reprocessing facility thus reprocesses spent fuel from both the Magnox and CANDU reactors. In one year, it can separate 73.16kg of weapons-grade plutonium.

Country B also operates two light-water reactors, which, unlike the Magnox and CANDU are linked to the national grid. These reactors were built by Country Z, which also supplies them with fuel. In total, Country B imports 72.48 tonnes of U_3O_8 per year. This is then fed into the two light-water reactors, with the spent fuel stored locally. The intention is to return the spent fuel to Country Z, for further processing or end-storage. Country B also has plans to build at least two more light-water reactors, and has announced plans to manufacture the fuel for these locally.

Over the course of 20 years, Country B has produced nearly 700kg of weapons-grade Pu239 from which it has made 116 plutonium-based warheads. Country B also holds significant stocks of LEU and reactor-grade plutonium. Its nuclear weapons are deployed as follows:

- 40 warheads deployed on land-based SRBMs.
- 36 gravity bombs carried aboard strike-fighter aircraft.
- 20 devices are regularly off-service for maintenance and safety checks.

Country B is a developing country. It has an adequate industrial infrastructure, but would need to import the high-precision equipment needed for advanced fuel cycle activities. Country B is not a member of any military alliance, and is suspected to have conducted illicit nuclear trade with another non-aligned state. It may also have ties to a black market nuclear network.

3.2.2 Applications of irreversibility

Similar to the previous example, the table below shows the five irreversibility levels set against the specific case of Country A:

Level 1	Dismantlement of warheads Ceasing production of all FM for weapons-uses	All 76 warheads and gravity bombs would be dismantled; Country B's Magnox and CANDU reactors would be shut down or converted to civilian uses; Reprocessing would be stopped, or Country B's reprocessing plant would be converted to civilian uses.
Level 2	Dismantlement of warheads Ceasing production of all FM for weapons-uses *Plus,* Destruction of warhead pits	As above, *plus,* All 76 warhead and bomb pits would be destroyed outright or re-integrated into Country B's civilian fuel cycle.
Level 3	Dismantlement of warheads; Ceasing production of all FM for weapons-uses; Destruction of warhead pits; *Plus,* Destruction of all stocks of HEU and plutonium (placed under monitoring while awaiting destruction); Monitoring of all nuclear facilities (as in NPT non-nuclear-weapon states), especially those involved in enrichment and reprocessing	As above, *plus,* All stockpiles of plutonium held by Country B would be destroyed (no enrichment facilities or HEU present in Country B), through burning in reactors/vitrification; IAEA safeguards would be applied to Country B's mines, conversion facility and LWRs; Verification measures would be applied to Country A's Magnox and CANDU reactors , and its reprocessing facility to ensure their continued shutdown (or these could be incorporated into IAEA safeguards, if already converted to civilian uses).

Level 4	Dismantlement of warheads; Ceasing production of all FM for weapons-uses; Destruction of warhead pits; Destruction of all stocks of HEU and plutonium (placed under monitoring while awaiting destruction); *Plus,* Elimination of enrichment and reprocessing facilities, (other facilities remain under monitoring)	As above, *plus,* Country B's reprocessing plant would be permanently decommissioned; Plans to locally manufacture fuel for Country B's two envisioned LWRs would be abandoned (since the LWRs would require LEU, which, if this fuel was to be manufactured locally, would require Country B to have an indigenous means of enriching uranium).
Level 5	Dismantlement of warheads; Ceasing production of all FM for weapons-uses; Destruction of warhead pits; Destruction of all stocks of HEU and plutonium (placed under monitoring while awaiting destruction); *Plus,* Elimination of *all* nuclear facilities, including reactors – not just those facilities involved in enrichment and reprocessing	All 76 warheads and gravity bombs dismantled; All stocks of HEU and plutonium destroyed; Country A's reactors would all be shut down, in addition to all other civilian nuclear facilities; Plans to build more LWRs would be abandoned (in addition, needless to say, to plans to manufacture the fuel for them locally).

Level 1

Dismantlement

In the case of Country B, the dismantlement of warheads would follow much the same lines as dismantlement in Country A. Warheads would be retired from service, de-mated from missiles or taken off aircraft delivery platforms and moved to dismantlement facilities—perhaps via interim storage—where they would be broken up into their constituent parts.

As with Country A, verification of dismantlement could be incorporated into the process to boost confidence that dismantlement was occurring exactly as declared. Once all 40 of Country B's nuclear warheads and all 36 of its nuclear gravity bombs had been dismantled through the separation of high explosives and fissile material components, Country B can be said to have disarmed itself of its nuclear weapon capability. At this stage it would still be able to put warheads back together with relative ease, but it would have no immediately-usable nuclear weapons in its possession.

Fuel cycle measures

Notably, in Country B there is a very clear distinction between the military and civilian fuel cycle. In Country A, a uranium conversion facility fed into both cycles, whereas in B the two remain isolated from one another. Within the military fuel cycle of Country B, two reactors are used to produce fissile material for use in nuclear weapons: a Magnox and a CANDU. To meet the disarmament irreversibility requirements of Level 1, Country B would need to not only dismantle its nuclear arsenal but also cease production of fissile material for weapons purposes, either by shutting these two reactors down or by converting them to civilian use. Both reactors could theoretically be linked into the national grid of Country B and used to increase the nuclear energy share of Country B's power supply. In addition, reprocessing would also be either stopped or the reprocessing facility kept operational but for civilian purposes only.

If the Magnox, CANDU and reprocessing plant were kept running but for civilian purposes then reversibility would, of course, be considerably easier than if they were shut down—especially if they were shut down without ongoing maintenance and, perhaps, with other disablement measures taken besides. *But*, even if these facilities were rendered disabled (with time for reversal at around a year even), at the first level of disarmament irreversibility Country B would still be in possession of 76 intact warhead pits ready to go back into warheads or bombs.

Extra measures

At Level 1, a decision to reverse disarmament would depend largely on the availability of tools, materials and expertise needed to reconstruct a nuclear warhead. Even if sites within Country B used for warhead assembly were eliminated, it might be assumed—or it would be hard to discount the possibility—that other sites within the country could be used for the assembly of warheads, a problem not (it might be added) unique to Country B. Given Country B's proven ability to manufacture complex weaponizable nuclear explosive devices (plutonium-based weapons being more technically challenging than uranium-based ones), the elimination of warhead assembly facilities at Level 1 might or might not retard rearmament prospects to a significant degree in Country B; far better, though, it can thus be argued, to address the amount and production of the vital components necessary for nuclear explosions within the country.

Level 2

At Level 2, disarmament irreversibility in Country B would be bolstered by the destruction of all 76 pits removed from the warheads and gravity bombs of the country's former nuclear arsenal. Once all pits were destroyed, rearmament would depend on the ability of Country B to re-manufacture pits for use in warheads. As a result, taking out pit manufacturing facilities at Level 2 would complicate irreversibility still further as these would have to be rebuilt, or other facilities converted to pit manufacture, before warhead pits could be created.

Level 3

Level 3 would see, in addition to the measures mentioned above, the destruction of all stockpiles of weapons-usable fissile material (plutonium in the case of Country B, which has no enrichment facilities or HEU) and the application of IAEA safeguards to all nuclear material and facilities within the country—including the Magnox, CANDU and reprocessing plant, if these were converted to civilian uses.

Destruction of stockpiles

As with Country A, Level 3 of the disarmament irreversibility model outlined in this report moves away from targeting only warheads to addressing warheads *plus* the capabilities behind the production of fissile materials for these weapons. At this level of disarmament irreversibility, capabilities are targeted both by the destruction of plutonium stocks in Country B (thus impairing its ability to remanufacture warhead pits) and through the application of verification measures on, among other facilities, those parts of its former military fuel cycle involved in the production of weapons-usable fissile material.

Application of safeguards

Country B could, of course, still reprocess spent fuel to separate plutonium, but with safeguards in place it would be harder for it to divert that material to a clandestine weapons production line. And if verification measures applied to Country B functioned as intended, the country would be discouraged from diversion by the risk of being caught out. As a developing country, Country B may be more susceptible to the imposition of punitive economic sanctions—to say nothing of military force—than the comparatively more developed Country A. Thus, assuming the state is and remains governed by a rational leader with 'normal' patterns of behaviour and decision-making, Country B's approach to cheating may be significantly influenced by considerations of the consequences that might result from such a course of action.

Level 4

At Level 4, Country B would—in addition to dismantling its warheads, stopping its production of fissile material for weapons, destroying the pits of all its warheads, destroying all its stocks of plutonium and placing all its nuclear activities under international safeguards—eliminate its reprocessing plant so as to impede its ability to produce weapons-usable plutonium in the future.

Elimination of reprocessing capability

Without a reprocessing capability, and with no stocks of weapons-usable plutonium or intact plutonium-based pits, the irreversibility of Country B's disarmament would be high. To re-arm, Country B would need to either rebuild a reprocessing plant and then begin the process of plutonium separation, or it could opt to go down the uranium bomb route by constructing an enrichment facility. But, as previously noted, this scenario is envisaging disarmament of a developing country that 'would need to import the high-precision equipment needed for advanced fuel cycle activities,' of which uranium enrichment is one. Thus, Country B's need for outside support—notwithstanding its links to black market networks—would likely also contribute to the irreversibility of its disarmament if Level 4 of the above model was reached.

Planned expansion of nuclear power

Another factor to take into account with regard to Country B is its intention to expand its civilian nuclear power industry in the future. A first observation might be that if the Magnox and CANDU reactors were converted to civilian uses, then Country B might reconsider its plans to construct two new LWRs. If not though, Level 4 of the disarmament irreversibility model would require Country B to abandon plans to manufacture fuel for these two reactors locally, as LWRs use three per cent enriched uranium. That would thus require Country B to develop an indigenous enrichment capability (not to mention a conversion plant for turning yellowcake into UF6 and a fuel fabrication facility for turning low-enriched UF6 into LWR fuel pellets).

Level 5

At the highest point of disarmament irreversibility, Level 5, Country B would eliminate all its nuclear facilities and stop all nuclear activities. At this level not only would plans to produce indigenous LWR fuel be abandoned but so would Country B's plans to build a pair of LWRs for energy purposes. At Level 5, all reactors would be permanently decommissioned and dismantled, with alternative energy arrangements sought for Country B's power needs. Again, as with Country A, warhead dismantlement, pit and fissile material destruction, followed by complete denuclearisation would provide the strongest guarantee of disarmament irreversibility envisaged in our model since the time and expense needed to reconstitute a nuclear arsenal from green fields would be large.

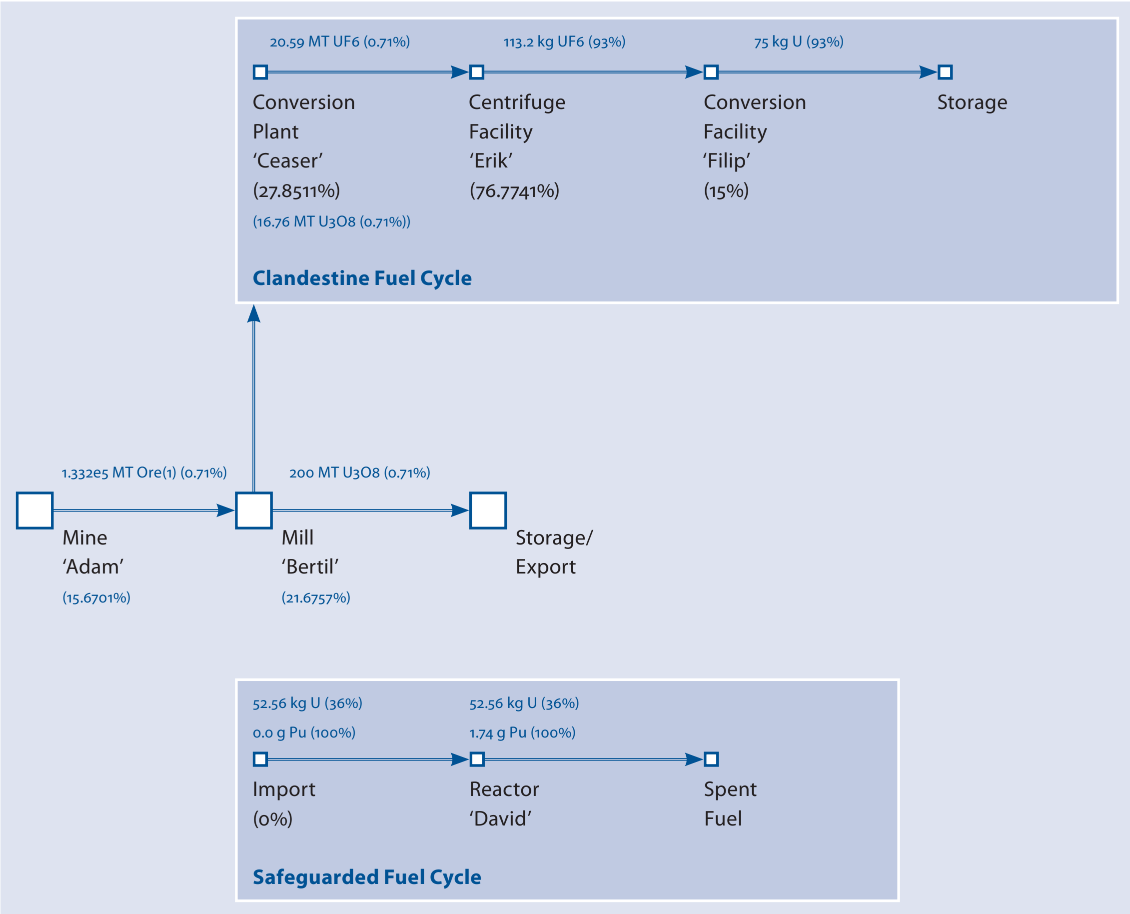
3.3 Country C: the errant non-nuclear-weapon state

Country C is a state with a nuclear fuel cycle still under development. It is a member of the NPT as a non-nuclear-weapon state. It currently has a small nuclear fuel cycle, including a research reactor and a small—secretly developed—enrichment facility. It has been discovered that this country has developed and manufactured a small arsenal of nuclear weapons, in contravention of its NPT undertaking not to do so. It is now being disarmed.

3.3.1 Nuclear activities in Country C

Country C operates one uranium mine, which supplies one uranium mill with some 133,200 tonnes of uranium ore per year. The total flow rate at this facility is 216.8 tonnes of yellowcake per year – which is

A diagram showing the fuel cycles and material flows in Country C



packed into 867 drums. Two-hundred tonnes is then exported to Country Z, giving the impression that Country C is simply mining and milling uranium for sale on international uranium markets.

However, each year, nearly 17 tonnes of yellowcake were transported to an undeclared, bench-scale uranium conversion facility. There, this material was converted into uranium hexafluoride gas, which was then transported to its undeclared enrichment facility. That facility worked using 5,000 URENCO G-2 centrifuges. At the facility, the uranium hexafluoride gas was enriched up to weapons-grade, and then processed into metal at an adjacent facility. Some 75kg of weapons-grade material was shipped off to the military every year, before Country C's secret weaponisation activities were discovered.

Separately, Country C also runs a small—and safeguarded—research reactor. This reactor produces 1.74g of weapons-grade plutonium per year; it is supplied by fuel from Country Z. All spent fuel from this reactor is stored next to it—and safeguarded also.

After ten years of production, Country C has accumulated 675kg of HEU, and built ten uranium-based nuclear gravity bombs. The intended delivery systems for these bombs was its squadron of light bomber aircraft.

Country C is not a member of any military alliance, but it is known to have connections to black market networks. Country C is a developing state, but has undergone rapid industrialisation in recent years.

3.3.2 Applications of irreversibility

The table below shows the necessary actions in Country C to meet the irreversibility requirements of Levels 1–5:

Level 1	Dismantlement of warheads; Ceasing production of all FM for weapons-uses.	All 10 gravity bombs would be dismantled; Country C's conversion facility, enrichment facility would be shut down or converted to civilian uses.
Level 2	Dismantlement of warheads Ceasing production of all FM for weapons-uses *Plus,* Destruction of warhead pits	As above, *plus,* All 10 gravity bomb pits destroyed
Level 3	Dismantlement of warheads; Ceasing production of all FM for weapons-uses; Destruction of warhead pits; *Plus,* Destruction of all stocks of HEU and plutonium (placed under monitoring while awaiting destruction); Monitoring of all nuclear facilities (as in NPT non-nuclear-weapon states), especially those involved in enrichment and reprocessing	As above, *plus,* All stockpiles of HEU held by Country C would be destroyed by downblending; IAEA safeguards would be applied to Country C's mines, conversion facility, and IRT research reactor; International verification measures would be applied to Country C's enrichment facility to ensure its continued shutdown (or continued use for civilian purposes, if converted).
Level 4	Dismantlement of warheads; Ceasing production of all FM for weapons-uses; Destruction of warhead pits; Destruction of all stocks of HEU and plutonium (placed under monitoring while awaiting destruction); *Plus,* Elimination of enrichment and reprocessing facilities, (other facilities remain under monitoring).	As above, plus, Country C's enrichment facility would be permanently decommissioned
Level 5	Dismantlement of warheads; Ceasing production of all FM for weapons-uses; Destruction of warhead pits; Destruction of all stocks of HEU and plutonium (placed under monitoring while awaiting destruction); *Plus,* Elimination of *all* nuclear facilities, including reactors – not just those facilities involved in enrichment and reprocessing	All 10 gravity bombs dismantled; All stocks of HEU destroyed; Country C's research reactor would be shut down, in addition to all other nuclear facilities

Country C's nuclear arsenal is considerably smaller than the arsenals of countries A and B. Moreover, whereas both A and B have multiple delivery systems for their nuclear devices, Country C's nuclear arsenal consists of only gravity bombs carried only on its squadron of light bomber aircraft. Before examining the irreversibility model above, an important observation here is that, in this specific case, controlling Country C's delivery vehicles might have a significant effect. If no other bomb delivery vehicles were realistically available in Country C (i.e. if other aircraft could not be modified to carry the bombs, which may or may not be likely), then modifying the country's light bombers to make them unable to carry the bombs—or even destroying them entirely—might prove a significant setback to any rearmament hopes.

That said, as noted many times in this report, controlling the acquisition of suitable weapons-usable fissile materials would provide for a far stronger degree of disarmament irreversibility than controls on delivery vehicles, or even measures taken with regard to Country C's warhead assembly facilities.

Level 1

At the first and lowest level of disarmament irreversibility, all ten of Country C's nuclear gravity bombs would need to be dismantled.

Dismantlement

The dismantlement of Country C's gravity bombs could either be conducted by Country C itself or by other, outside, actors seeking to disarm Country C in the interests of peace and security.[56] Obviously, the principal complicating factor with regard to this state is its past deception over exports of nuclear material. Notwithstanding concerns over possible 'baseline' issues,[57] if Country C was to conduct dismantlement operations itself, verification of that dismantlement by outside actors might be seen as essential. Dismantlement *without* outside verification might not be acceptable to other countries with an interest in ensuring Country C's nuclear disarmament.

Fuel cycle measures

At Level 1, the clandestine fuel cycle of Country C—and especially its enrichment facility—would also need to be closed down or converted to civilian uses (though this latter option may be considered unacceptable given Country C's past behaviour). To return to the baseline problem, however, even if the enrichment facility was shut down, without substantial monitoring and verification efforts it would be difficult for other states to be sure that no other clandestine enrichment facilities existed elsewhere in Country C.

Level 2

Moving on to Level 2, which adds pit destruction to the dismantlement of Country C's bombs and the halting of fissile material production for military uses, a similar verification requirement as at Level 1 will likely emerge. That is: others, particularly those states in the regional vicinity of Country C will want to be assured that the ten pits from Country C's gravity bombs were properly destroyed. At Level 2, reversibility would depend largely on Country C's ability to re-enrich uranium for use in bombs, which would depend on the state of Country C's enrichment facility (i.e. whether it had been shut down, shut down and disabled, or converted to civilian uses) and the presence, or absence, of other enrichment facilities elsewhere in the state.

Level 3

At Level 3, Country C would, in addition to dismantlement and all the other measures identified at Levels 1 and 2, destroy all stocks of HEU and allow IAEA safeguards to be applied to all its nuclear sites and facilities.

HEU destruction

As in the cases of Countries A and B, Level 3 requires the destruction of all stocks of weapons-usable within possession of a state in question. In Country C, this would likely raise questions as to the extent of HEU holdings. Given Country C's track record of deception, many states may well assume that Country C is in possession of more weapons-usable fissile material than it declares to be the case, as seen in the case of North Korea, where disputes over the amount of plutonium produced at the Yongbyon plant continue to this day. How to address the baseline problem, particularly in states with poor book-keeping over the amount of fissile material they have produced, perhaps intentionally so, is well-recognised as being one of the most difficult challenges on the path to a world without nuclear weapons.

56 This is not to say that the disarmament of Countries A and B could only be conducted by their own nationals, merely to emphasise that given the revelation of Country C's clandestine weapons production, a stronger case for outside intervention may exist.

57 Meaning discrepancies between what Country C declares and what actually exists. That is, in this case, does Country C really only possess ten gravity bombs, or is an eleventh or twelfth, or another ten even, hidden away elsewhere in the country?

Application of safeguards

Amongst other benefits, safeguards would help to guard against the enrichment of uranium for military ends at Country C's enrichment facility, if that facility was kept operational for civilian purposes.

In Country C's case, as an NPT non-nuclear-weapon state, a Comprehensive Safeguards Agreement should already be in place. And indeed, even before the revelations of nuclear weapons development, Country C did run a safeguarded fuel cycle centred on its research reactor. In the case of Level 3 here, it might be prudent to press for the application of an IAEA Additional Protocol in Country C, which would allow IAEA inspectors to have not only broader information on the entirety of Country C's nuclear activities but also wider-ranging rights of access (at shorter notice periods) to nuclear sites around the country. Assuming that Country C has little choice but to submit to the wants of others, perhaps at risk of overwhelming military force if it refuses to comply, one way to encourage Country C's peaceful acceptance of an Additional Protocol might be to tie acceptance of that instrument to the right for Country C to keep its enrichment facility. In other words, if Country C wanted to turn its clandestine enrichment facility to legitimate civilian purposes then it could only do so through acceptance of full IAEA safeguards—Additional Protocol and all.

In terms of reversibility, at Level 3, for Country C to reconstitute a nuclear arsenal, it would first have to enrich enough uranium to weapons-grade to implant into a warhead, or warheads, which would either mean breaking safeguards at its enrichment facility or by using a separate, hidden (and thus unsafeguarded) enrichment facility somewhere else in the state.

Leaving aside the baseline HEU problem, if all weapons-usable fissile material stocks within Country C were destroyed and IAEA safeguards applied to all parts of its nuclear infrastructure, in addition to all measures identified at Levels 1 and 2, then the rearmament ability of Country C would be highly dependent on its ability to re-enrich uranium faster than an effective international response to a further breach of the NPT could be mounted. It seems improbable that Country C would be able to do so, given the time taken to enrich uranium to weapons-grade in a great enough quantity to fuel a nuclear bomb, let alone several.

Level 4

At the fourth level of disarmament irreversibility, Country C would be additionally required to eliminate its enrichment facility. Assuming that no other clandestine enrichment facilities exist elsewhere in Country C, then removing the enrichment facility would aid irreversibility by requiring such a facility to be rebuilt before the process of manufacturing HEU could begin.

Level 5

To achieve irreversibility at Level 5 of the model outlined in this report, Country C would have to decommission all of its nuclear facilities. This would involve the dismantling and decontamination of both its research reactor and its enrichment facility. The combined effect of decommissioning, which can take many years and even decades to reach completion, will set back rearmament prospects considerably. To rearm, Country C would have to either rebuild the means to produce weapons-usable fissile material, and then operate the facilities involved for a sufficient period of time to produce enough material for bombs, or build up a completely new military fuel cycle—which might take longer, and require technical knowledge not indigenously present in Country C.

In addition to the loss of all its nuclear facilities, the application of measures that would eliminate its stocks of HEU—thereby reducing the risk that such material can be used to manufacture new nuclear bombs or warheads—would ensure that Country C has no ready means to reconstitute its nuclear weapons capability. Level 5 would likely see the time needed for rearmament expanded to perhaps a decade or more.

4. Conclusion

Nuclear disarmament is not a binary state. A country can be disarming while not being yet fully disarmed. The process to achieve the final abolition of an entire class of weaponry may still be called disarmament. But weapons can always be produced. Even a fully disarmed stated can rearm, if there is the political will and resources to do so. A state that controls the raw materials, the necessary industrial infrastructure, and technical and scientific knowledge will always be able to hedge against the loss of the nuclear weapons capacity. All disarmament actions are, therefore, reversible. But some are more easily reversible than others. In nuclear disarmament, it may be rather more suitable to talk about *unarmed states* rather than *disarmed states*.

Is there, in fact, any utility at all in talking about *irreversible disarmament* if all disarmament actions are reversible? To claim that a disarmament action is irreversible only if it is incapable of being changed may be true to the dictionary meaning, but it is a politically, diplomatically and technically problematic use of the term. After all, many—if not all—of the steps taken by governments examined in our annexed case studies can be reversed.

Some, such as several of the steps taken by the US and Russian governments over the past 40 years (see Annex I), can be reversed with relative ease. Beside vast stockpiles of weapons-usable materials, these countries also preserve large military-industrial complexes, and host a wealth of scientific and technical ability. Here, whether a disarmament action can be reversed hinges only on political will.

Libya (examined in detail in Annex III) lies towards the other end of the spectrum. Libya is fairly resource-strapped, has limited industrial means and limited raw materials. In addition, it is a country that may not have much scientific and technical knowledge to produce a nuclear explosive. Even if the political will was to emerge, which given the recent fall of the Gaddafi regime seems highly unlikely, the effort needed to establish and run a nuclear weapons programme would probably be monumental.

That said, however, the case of North Korea (see Annex II) shows that even states with limited resources may seek to arm themselves with nuclear weapons if there is enough political will to do so. An industrial undertaking of this size will mean that national resources are diverted from other economic sectors, perhaps at high cost. But the North Korean case shows that this step can nevertheless be taken if the national interest, however defined, so dictates and the development of nuclear weapons is—for whatever reason—seen to be of pressing concern.

4.1 The irreversibility spectrum

Our study strongly suggests that the term *irreversibility* needs a functional definition substantially different to its common dictionary definition when applied to the disarmament context. It may be better to consider irreversibility in terms of the costs and difficulty of rearmament. The question, then, becomes not whether nuclear disarmament could be reversed, but how costly and difficult would it be to do so. This means that irreversibility measures can be judged on a scale. Actions that would require huge national effort to reverse are placed on one end of the scale. At the other extreme are those efforts that could be reversed by little more than a simple political decision.

To put it more concretely, measures addressing only the dismantlement of nuclear explosive devices (where the nuclear pits are kept intact) could be put at the low end. It will, after all, be relatively straightforward for a state to rearm if fissile material is kept stored in weapon shapes. Especially so if all means of production, such as nuclear warhead production sites, are kept well-maintained. Without any intact nuclear warheads, the state in question may be technically disarmed, but perhaps to say it is *unarmed* reflects the ease of reversal rather better. The cost and effort involved in reconstituting the state's nuclear arsenal from this point is relatively small, and could likely be taken fairly quickly.

At the other end of the scale lies the complete abandonment of all nuclear weapons as well as their means of production. This means that all fissile materials have been made unusable in nuclear explosive devices. That material may have been destroyed or sent out of the state's territory. In addition, the state has decommissioned its entire nuclear fuel cycle infrastructure, so losing its industrial capacity to produce new batches of material. While the knowledge to make nuclear weapons will linger on for some time, the applied arts of manufacturing nuclear weapons may eventually fade away.

This report indicates that if all nuclear warheads in a country were dismantled then the irreversibility of that disarmament would depend, above all, on the following:

- The amount of weapons-usable fissile material in the state in the form of intact (and unstuffed) pits; and, thus, able to be directly used—or re-used, as the case may be—in warheads;
- The amount of weapons-usable fissile material in the state in forms not immediately able to be implanted in weapons (i.e. in non-pit form, whether that material is safeguarded or not);
- The capabilities of the state to produce weapons-usable fissile material and, separately, to fabricate that material into pit forms that can be implanted into warheads;
- The existence or absence of warhead assembly facilities within the state, where pits and the various non-nuclear components of a warhead would be combined; and
- The availability of delivery systems that could deliver warheads to a target in a reliable fashion.

Short of the 'green-field' abandonment of all nuclear infrastructure, a state towards the 'high' end of the irreversibility spectrum will be one without any means whatsoever to produce nuclear weaponry. This would require that the following steps are fully implemented:

- The destruction of the fissile material components of dismantled warheads;
- The disposition of all weapons-usable fissile material within a state (i.e. not just those from weapons);
- The elimination, disablement or conversion to civil uses of all facilities involved in the final assembly of warheads and the manufacture of warhead pits;
- The elimination, or the severe disablement, of all facilities used in the production of potentially weapons-usable fissile materials (i.e. enrichment and reprocessing plants);
- The placement of all fissile materials under international safeguards; and
- The elimination or conversion to non-nuclear roles of all nuclear delivery vehicles.

Cumulatively, the above steps would make the process of nuclear rearmament costly, difficult, time-consuming and more than likely to be detected by the international community. For these reasons it entails a high degree of irreversibility.

Not all of the points listed above would necessarily be important for every state, though. A state with many intact warhead pits would not need a pit manufacturing plant to the same extent that a state with no pits but a considerable amount of HEU would, for example. Or any need even, if it judged its current pit stockpile to be sufficient to counter any current or future threats.

The absence of some types of materials and industrial capacity will have greater relevance for irreversibility than the absence of others. A state that holds all building blocks for a weapons programme except, for instance, a warhead assembly plant, will find it easy to rearm. A state that has a warhead assembly plant but no fissile material production capacity is facing a significant industrial challenge. It may be something of a truism to say that acquiring enough weapons-usable fissile material is the hardest part of nuclear bomb-making, but in the context of disarmament irreversibility it needs to be stressed.

One of the most complex factors when considering disarmament irreversibility is the vast array of different possible 'end states'. This is especially true of countries with a large and complex nuclear infrastructure. Particular difficulties arise when a country has both a civilian and a military fuel cycle, and especially where a country owns 'sensitive' dual-use nuclear technologies (i.e. enrichment and/or reprocessing facilities). Nuclear disarmament is far more reversible in scenarios where countries are allowed to maintain control over enrichment and reprocessing than in scenarios where these technologies have been given up.

4.2 Case study lessons

Our review of past arms control and disarmament practice suggests that the pursuit of irreversible nuclear disarmament has either been largely glossed over—as in US-Russian arms accords—or addressed only in indirect terms—as in the case of North Korean nuclear 'disablement'.

In the US-Russian context, no treaty has yet been agreed between the two countries to require even one warhead to be taken apart. Its relevance to irreversibility might therefore be somewhat questionable. Especially so since both countries, despite reducing their ability to deliver nuclear warheads to their targets, preserve their ability to quickly revert to a prior state of affairs. Both still own large stocks of fissile material, and maintain large military-industrial complexes besides civilian nuclear industry, which may be pressed into military service should the national interest so dictate.

However, it is possible to draw inspiration from some of the ideas put forward in US-Russian disarmament discussions. In the 1990s, for instance, both governments suggested that nuclear warheads ought to be addressed in future agreements in order to increase irreversibility. There are obvious problems incorporating verifiable controls on warheads into arms reduction treaties. The number of treaty-accountable items would be far more than before, and their small size and portability would make it difficult to verify any baseline declarations. Despite these challenges, it stands to reason that a situation where warheads have been taken apart is less reversible than one where they remain intact. And the cost and difficulty to reverse the situation increases further still if the materials within the warheads have been destroyed or transferred into the civilian nuclear fuel cycle.

The North Korean case suggests, perhaps above all, and at the risk of stating the obvious, that for 'disablement' actions to impact most heavily on irreversibility, they must be robust enough to ensure that they cannot be readily undone. The closer disablement gets to elimination (bearing in mind that certain disablement steps, or combinations of them, would effectively 'write-off' facilities), the more irreversible they become. The case also shows that political factors will heavily influence the extent of disablement actions that can be taken in countries that are not militarily defeated and/or forced to comply with decisions taken by others.

What is shown most clearly of all in the Libyan case is the importance of knowledge to weaponisation endeavours. A lack of expertise forced the country to turn to the illegal procurement network of A.Q. Khan. It also formed a key obstacle to the fulfilment of Libya's nuclear weapons efforts. Indeed, it is a point raised in the South African case also (see Annex IV), where some of the scientists involved in that, successful, programme went on to collaborate with the Khan network. How to address the nuclear weapons knowledge and expertise that will remain in a disarmed state after disarmament is a point that requires considerable further attention.

In addition, both the examples of Libya and South Africa illustrate that for disarmament to be successful and enduring, a level of cooperation from the disarming state in question is important. In the case of North Korea, obstruction from the regime in Pyongyang has on many occasions set back multilateral efforts to roll back the DPRK's nuclear weapons programme.

4.3 Overall observations

This report has understood 'disarmament' to mean the absence of *any* usable nuclear weapons in a state's possession. In this, it has been informed by Steve Fetter's understanding that nuclear disarmament requires, at a minimum, the dismantlement of all nuclear explosive devices under the national control of a state. In other words, for a state to have been 'disarmed' of its nuclear weapons capability, it would need to have dismantled its entire existing arsenal of nuclear warheads (or have had them dismantled by others). It has not addressed the political, societal, legal and military-technical aspects of the issue, which are the subject of a companion study by SIPRI.

The use of the word 'existing' is important. As this report has shown, there are two different dimensions to a country's nuclear arsenal that disarmament actions can take into account. The most fundamental dimension is, obviously, the state's nuclear arsenal itself. The second dimension is the supporting infrastructure that could potentially be drawn on to produce new nuclear weapons in the future. Addressing the second without addressing the first would not constitute disarmament (for obvious reasons: the state would still possess a nuclear arsenal). Addressing the first without the second *would* constitute disarmament—*but the ability to produce more weapons in the future would significantly affect the irreversibility of that disarmament*.

It is this point that highlights the *existence of a strong link between disarmament irreversibility and the need to address not only those warheads currently in a state's possession, but a country's ability to produce such weapons*. Many of the steps outlined in this report are framed in post-disarmament terms. But not all necessarily require a country to be fully disarmed before they can begin to be implemented. Taking steps to limit, reduce and control stocks of weapons usable fissile materials—or to eliminate the means of their production (i.e. enrichment and reprocessing facilities), perhaps through incentivising multilateral fuel cycle arrangements—are all steps that could be taken today with a view to aiding disarmament irreversibility in the future. For that matter, since the dismantlement of warheads is one of the central pillars of this report, its incorporation into future arms reduction treaties help not only the short-term irreversibility of any such agreements but perhaps also set a precedent for other treaties besides.

The 'endurance of knowledge' of nuclear weaponisation and the impact of verification are, of course, important factors also. Knowledge and expertise provide a critical link between nuclear technology and materials and a workable nuclear explosive device. And verification, if it functions properly as a deterrent, can play a role in changing the calculations of states over rearmament decisions.

Ultimately, this report has argued that, given the underlying reversibility of all disarmament actions, it is perhaps best to frame irreversibility in terms of the ease of rearmament. Irreversibility in disarmament can thus be considered to lie along a continuum, with highly reversible actions at one end and a combination of actions making rearmament highly difficult and costly at the other. Along this continuum, progressively higher degrees of irreversibility will result in progressively greater utility in terms of predictability of strategic balances and, by extension, strategic stability. *Steps to promote disarmament irreversibility will breed greater reassurance among states that disarmament cannot be readily reversed.* Obviously, the more steps taken, and the more difficult reversal becomes, the more reassurance—and stability—there will be. Achieving 'irreversible' nuclear disarmament can thus arguably play a significant role in the furtherance and maintenance of stable arms control and/or disarmament arrangements.

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Annexes

Annex I: Irreversibility between the US and Russia

In the case of nuclear arms agreements between the United States and what is now Russia, two points are particularly important: firstly, that these fall into the category of nuclear arms *reduction* agreements, thus falling some way short of disarmament; and secondly, as will become clear, even within the context of nuclear arms reductions, neither governments in Washington or Moscow have to date made much of an effort to ensure that treaties incorporate provisions for irreversibility.

That is not, however, to suggest that these treaties do not hold important lessons for this study. On the contrary, both the US and Russia have in the past recognised the importance of the concept of irreversibility. What's more, treaties between them contain aspects relevant to this study, and perhaps most importantly of all, examining where bilateral accords between the two have allowed for *re*versibility makes it possible to identify how treaties more irreversibility-inclined might be constructed in the future.

Past nuclear arms treaty negotiations between governments in Washington and Moscow have tended to focus on nuclear warhead delivery vehicles, as opposed to nuclear warheads themselves—a significant omission when irreversibility begins to be taken into account. Once produced, actual warheads have generally not been considered suitable candidates for direct, verified control—and especially destruction—because of their small size, which makes them easy to hide, and the secrecy concerns that surround them.

The introduction, in the early 1960s, of reconnaissance satellites carrying high-resolution cameras, sensing technology and other 'National Technical Means' (NTM) made it possible to monitor both the numbers and types of strategic delivery systems. As a result, delivery vehicles—to which certain numbers of warheads could be attributed—came to be used to determine and limit the size of strategic nuclear arsenals.[58]

SALT I

These new technical capabilities enabled the US and the USSR to negotiate between them, as part of the first series of Strategic Arms Limitation Talks, or SALT I (which ran from November 1969 to May 1972):

- An 'Interim Agreement' of five-year duration prohibiting the construction of additional fixed land-based intercontinental ballistic missile (ICBM) launchers and freezing the levels of submarine-launched ballistic missile (SLBM) launchers and submarines to the numbers 'operational and under construction' at the date of signature; and
- The Anti-Ballistic Missile (ABM) treaty, unilaterally abrogated by the US in 2002, which prohibited the deployment of nationwide ABM systems and placed a variety of restrictions on qualitative improvements in ABM technology.

58 *Monitoring Nuclear Weapons and Nuclear-Explosive Materials: An Assessment of Methods and Capabilities*, National Academy of Sciences (The National Academies Press, 2005), 21.

Under the ABM treaty, the permitted deployments of ABM systems were limited to two sites in each country—one for the protection of the national capital city, and the other for the protection of an ICBM complex elsewhere—that were required to be at least 1,300km apart.[59] No more than 100 fixed ABM launchers and 100 single-warhead interceptor missiles could be deployed in an ABM deployment area, the treaty stated. ABM radars were not to exceed specified numbers and were subject to qualitative restrictions. Early-warning radars were allowed but the treaty limited the deployment of such radars to locations along the periphery of the national territory, where they had to be oriented outward. The treaty also banned the development, testing and deployment of mobile ABM systems and components, and of multiple-launch or rapidly reloadable ABM launchers.

For our consideration of irreversibility, though, it is the Interim Agreement that is more directly relevant. As noted above, this agreement called for a five-year freeze on the number of fixed land-based ICBMs and a further cap on the construction of SLBM launchers and submarines.[60] But a freeze on construction, and especially a temporary freeze (over a relatively short-term period) where it can be assumed that the facilities involved in such construction would be maintained and ready to go back into action at short notice, is far from an irreversible step. The Interim Agreement explicitly provided for verification through the use of NTM, but as was noted elsewhere in this report, verification measures can do little but watch and, through the possibility of adverse consequences, deter cheating.

SALT II

With the SALT Interim Agreement and ABM treaty done deals—and in accordance with Article VII of the Interim Agreement, which called on its parties to 'continue active negotiations' for further limitations on strategic offensive arms—November 1972 saw the start of SALT II negotiations.

The goal of the SALT II process was to establish permanent ceilings on strategic aircraft, ICBMs and SLBMs. As noted by the US State Department: 'The principal US objectives as the SALT II negotiations began were to provide for equal numbers of strategic delivery vehicles for the sides, to begin the process of reduction of those delivery vehicles, and to impose restraints on qualitative developments which could threaten future stability.'[61]

The essential elements of SALT II were agreed at the 1974 US-Soviet summit meeting in Vladivostok where, in a joint statement, the two countries established the principle of equal ceilings on strategic delivery vehicles. There, they agreed to an aggregate limit of 2,400 ICBMs, SLBMs and heavy bombers, of which only 1,320 ICBMs and SLBMs could be equipped with so-called multiple independently targetable re-entry vehicles (MIRVs).[62]

SALT II was eventually signed by US President Jimmy Carter and Soviet General Secretary Leonid Brezhnev in Vienna in June 1979. It set an initial aggregate limit of 2,400 strategic delivery vehicles (defined by the treaty as ICBM and SLBM launchers, heavy bombers and air-to-surface missiles) as well as several sub-limits applying to the number of MIRV systems that each side could own (1,320 MIRVed ballistic missiles and heavy bombers equipped to carry long-range cruise missiles; 1,200 MIRV ballistic missile launchers, of which only 820 could be launchers of MIRVed ICBMs) The ceiling on aggregate delivery vehicles was to be lowered to 2,250 in 1981.[63]

59 In 1974, in a protocol to the ABM treaty, the US and the Soviet Union agreed to further limit the allowed level of ballistic missile defence by reducing the number of locations that could be protected by ABM systems to one.

60 *Interim Agreement between the United States of America and the Union of Soviet Socialist Republics on Certain Measures with Respect to the Limitation of Strategic Offensive Arms*, 1972.

61 US State Department overview of SALT II: http://www.state.gov/www/global/arms/treaties/salt2-1.html (accessed 21 November 2010).

62 Jozef Goldblat, *Arms Control: A Guide to Negotiations and Agreements*, Sage Publications,1996, 59.

63 Goldblat, *Arms Control,* 60.

In addition to these limits, SALT II called for a freeze on the number of re-entry vehicles aboard existing ICBMs—with a future limit of ten on the one new type of ICBM that the treaty allowed each side to develop and test—as well as for limits of 14 re-entry vehicles on SLBMs and ten on air-to-surface ballistic missiles. Limits were also placed on the number of air-launched cruise missiles (ALCMs) that could be carried aboard heavy bombers, and ceilings set on the launch- and throw-weight of 'light' and 'heavy' ICBMs.[64] Verification was again to be achieved through the use of NTM.[65]

According to the treaty: 'Strategic offensive arms which would be in excess of the aggregate numbers provided for in this Treaty as well as strategic offensive arms prohibited by this Treaty shall be dismantled or destroyed' according to procedures to be established by a consultative commission.[66] As Jozef Goldblat has noted, the aggregate limit on delivery vehicles set by the SALT II treaty would have required the Soviet Union to dismantle, without replacement, around 250 operational missile launchers or bombers, while the United States would have had to dismantle 33.[67]

Ultimately, however, the Soviet invasion of Afghanistan in late 1979 scuppered efforts to secure US Senate ratification of the treaty, even though both sides declared that they would comply with its provisions regardless. Only in 1986—after declaring in 1984 and 1985 that the Soviet Union had violated its political commitment to observe the SALT II treaty—did US President Ronald Reagan announce that, from then on, the United States would 'base decisions regarding its strategic force structure on the nature and magnitude of the threat posed by Soviet strategic forces and not on standards contained in the SALT structure.'[68]

INF and START I

During the early 1980s, the US and the USSR began negotiations for both the Intermediate-Range Nuclear Forces (INF) accord, signed in December 1987, and the first Strategic Arms Reductions Treaty (START I), which was eventually concluded in 1991.

The INF treaty, which outlawed all US and Soviet intermediate- and shorter-range missiles, also broke new ground by requiring on-site monitoring of the destruction of all such missiles and their launchers.[69] In addition, under INF—which entered into force in 1988—relevant US and Soviet missile manufacturing plants were placed under continuous portal and perimeter monitoring (including x-ray examination of large containers exiting the plant) to make sure that banned missiles were not being manufactured. The INF treaty marked the first ever occasion that the Soviet Union had agreed to on-site verification activities. Nuclear warheads removed from missiles banned by the treaty could be placed in storage, however, and, as the National Academy of Sciences (NAS) has noted, some may have been redeployed on other weapon systems.[70]

While the INF treaty is an undoubtedly important accord in the realm of delivery systems, given those systems' somewhat 'complementary' nature in respect of irreversibility, its relevance to the subject of this report is inherently limited. Warheads—which, as noted, the INF treaty left untouched—could still be

64 Ibid.,60–61.

65 US State Department overview of SALT II: http://www.state.gov/www/global/arms/treaties/salt2-1.html (accessed 21 November 2010).

66 *Treaty Between The United States Of America And The Union Of Soviet Socialist Republics On The Limitation Of Strategic Offensive Arms, Together With Agreed Statements And Common Understandings Regarding The Treaty*, 1979.

67 Goldblat, *Arms Control,* 61–61.

68 US State Department overview of SALT II: http://www.state.gov/www/global/arms/treaties/salt2-1.html (accessed 21 November 2010).

69 *Treaty Between The United States Of America And The Union Of Soviet Socialist Republics On The Elimination Of Their Intermediate-Range And Shorter-Range Missiles* Article X.i.7, 1987.

70 *Monitoring Nuclear Weapons and Nuclear-Explosive Materials*, National Academy of Sciences, 22.

placed on other types of missiles or delivery systems such as bombers. And as Goldblat has written: 'The INF treaty eliminated only a small fraction of the nuclear delivery vehicles possessed by the United States and the Soviet Union.'

For its part, START I required that after a seven-year implementation period from the date of its entry into force, which finally happened in 1994, each side could possess no more than 1,600 deployed strategic offensive delivery vehicles, corresponding—according to the various counting rules set out in the treaty—to no more than 6,000 'attributed' warheads. The 6,000 warhead limit entailed further limits of 4,900 warheads attributed to deployed ICBMs and SLBMs, 1,100 warheads attributed to deployed ICBMs on mobile ICBM launchers and, in the Soviet case, 1,540 warheads attributed to 154 deployed heavy ICBMs. (The US had no heavy ICBMs.)

As Amy Woolf has noted, under the START I treaty, the US and Russia did not actually count the number of deployed warheads. Instead, each party counted the number of launchers (ICBM silos, SLBM launch tubes and heavy bombers) deployed by the other side. They then assumed that each operational launcher carried an operational missile, and that each operational missile carried a certain number of attributed warheads. The number of warheads attributed to each missile or bomber was listed in an agreed memorandum of understanding and was the same for all missiles and bombers of a particular type; there was no attempt to take into account the possibility of different numbers of actual warheads deployed on individual delivery vehicles.[71]

START I, then, was a means of reducing the number of deployed warheads via delivery vehicles via, again, launchers. In most cases, the number of warheads attributed to each type of ICBM or SLBM was equal to the maximum number of warheads that each type of missile had been tested with. START did, however, permit the parties to reduce the number of warheads attributed to some of their ballistic missiles—a process known as 'downloading'.

During the negotiation of START I, the main argument for downloading was that the ability to spread the total number of warheads allowed by the treaty over more missiles would allow for strategic nuclear forces to be more flexibly configured. As Dunbar Lockwood noted in 1991: 'If the two sides deploy a larger number of ballistic missiles, each with fewer warheads, they will "spread their eggs into more baskets," enhancing the survivability of their retaliatory forces.'[72]

Downloading, as Gerald Marsh has noted, could also save money, for 'instead of building new missiles designed to carry fewer warheads, a country can simply reduce the number of warheads on the missiles it already has.'[73] And then there was, or is, also the argument that reducing the number of warheads deployed on land-based MIRVed missiles would enhance stability in a crisis situation, since the more warheads thought to be aboard any particular ICBM, the more inviting a target that particular missile becomes. As Goldblat puts it: 'Strategically, downloading diminished the value of each MIRVed missile as a target, reducing the incentive to strike first.'[74]

The obvious problem, though, is that downloading creates a possibility for rapid 'uploading', i.e placing removed warheads back onto missiles in a treaty breakout scenario. Article III of START I sought to mitigate such concerns by setting limits on the extent to which parties could download their existing ballistic missiles (no downloading was permitted on new types of missiles). It provided that each party had the right to be credited with download reductions up to an aggregate level of only 1,250 at any one time. Missiles could also not be downloaded by more than four warheads.

71 Amy F. Woolf, 'The New START Treaty: Central Limits and Key Provisions', Congressional Research Service, 23 December 2010, 5.

72 Dunbar Lockwood, 'Missile-aneous Issues Settled at Last', *Bulletin of the Atomic Scientists*, September 1991, 13.

73 Gerald Marsh, 'The Ups and Downs of Downloading', *Bulletin of the Atomic Scientists*, November 1991, 21–23.

74 Goldblat, *Arms Control*, 67.

During discussions on downloading, the Soviet SS-N-18 submarine-launched ballistic missile emerged as a particularly contentious item. In 1987, the US and the USSR agreed that the SS-N-18 was to be attributed with seven warheads. Later on though, in 1990, the Soviet Union announced that all SS-N-18s had been reduced to three warheads and that all seven warhead front ends had been destroyed. In December 1990, a letter from the Soviet foreign minister, Eduard Shevardnadze, to the US Secretary of State James Baker offered an explicit assurance that the Soviet Union had indeed retired seven warhead SS-N-18 front ends, that the stockpile of such front ends had been entirely destroyed, that the USSR no longer produced them nor intended to produce them in the future and that all SS-N-18s were not only equipped with three warhead front ends but that these were designed in such a way that carrying any more than three would be impossible.

As a result, as part of the overall agreement on downloading the parties agreed to treat the SS-N-18 missile as a special case. In the memorandum of understanding accompanying the START I treaty the missile was attributed with three warheads, but the four warheads that the Soviets had taken off their SS-N-18s were counted as part of the USSR's permitted aggregate downloading total of 1,250. Hence, Article III of the treaty notes that the Soviet downloading limit would consist of 'four multiplied by the number of deployed SLBMs' of the SS-N-18 type, plus 'the reduction in the number of warheads attributed to ICBMs and SLBMs of no more than two other existing types.'[75]

Ultimately, whether downloading is all critical is arguable. In Lockwood's reckoning, the significance of downloading in START I negotiations was 'always overstated', since, he argued then, military significant degrees of cheating on downloading are easily detectable by satellite reconnaissance. 'But', he recalled, 'as former chief US negotiator Richard Burt put it, "The last remaining issues in a negotiation take on a political importance that is disproportionate to their military importance because neither side wants to be seen in the last stage . . . as caving in."'[76]

In terms of verification, START I included a range of intrusive verification measures, including NTM, various types of on-site inspections (including ten re-entry vehicle inspections per year), exhibitions, data exchanges and notifications, as well as the right to conduct continuous portal and perimeter monitoring of mobile ICBM assembly facilities. The treaty included, again, explicit provisions not to impede NTM verification.

An attached protocol to the treaty set out procedures for the elimination, or conversion, of strategic delivery vehicles and launchers—in order to remove them from accountability under the treaty—in great detail. But, critically, and as with the INF treaty, nothing in START I required either the control or destruction of the actual nuclear warheads taken off deployment as a consequence of the reductions called for. Nor did START I prohibit either party from making qualitative improvements to their strategic weapon arsenals as older warheads were brought out of service. With warhead dismantlement identified elsewhere in this report as the baseline for 'disarmament', the point, that is, at which considerations of disarmament irreversibility can begin (if carried out on *all* nuclear explosive devices), START I fell well short of that mark. Although it is probable that some, perhaps many, warheads removed from deployment as a result of START I were dismantled by the US and Russia, nothing in the treaty compels them to do so.

Unilateral steps and START II

In September 1991, less than two months after START I was signed, the US—under the administration of President George H.W. Bush—announced a number of unilateral steps to supplement the formal treaty

75 START I article-by-article analysis: http://www.dod.gov/acq/acic/treaties/start1/start1_art_14.htm (accessed 21 November 2010).

76 Lockwood, *Missile-aneous Issues Settled at Last*.

process, including the intention to dismantle and destroy all nuclear warheads designed for use in short-range ballistic missiles, the removal of all US strategic bombers from day-to-day alert readiness and the de-alerting of all ICBMs scheduled for deactivation under START I.[77]

In return, the Soviet president, Mikhail Gorbachev, reciprocated by announcing comparable de-alerting measures of his own, as well as the intended repatriation of all Soviet non-strategic nuclear weapons from Eastern Europe and other Soviet republics, and the intention to dismantle all Soviet nuclear artillery and ground-launched tactical nuclear weapons. In January 1992, with the Soviet Union having collapsed in the interim, the new Russian president, Boris Yeltsin, extended Gorbachev's pledge to include the dismantlement of half of Russia's air-launched tactical nuclear weapons as well as half of its nuclear weapons designed for use in anti-aircraft missiles and one-third of its sea-launched non-strategic nuclear arms.[78]

(As the NAS have noted, although these unilateral steps were not verified by the other party, 'it appears that all nuclear weapons outside Russia were successfully repatriated,' and both sides have made subsequent declarations as to the portion of these commitments that have been fulfilled.)[79]

Two years later, in January 1993, Yeltsin and Bush signed the second START agreement, which called for further reductions in the number of deployed strategic warheads (down to between 3,000 and 3,500 through, as with START I, verifiable reductions in delivery vehicles), as well as the 'de-MIRVing' of all ICBMs. As far as downloading—especially important given the ban on MIRVed systems—was concerned, START II generally followed the same rules as START I, with a few exceptions, notably that the 1,250 aggregate downloading limit was removed and the right to download up to 105 of one type of existing ICBM by up to five warheads was included.[80]

START II was to have relied on the same verification system as START I. As in the past, though, START II contained no provisions requiring the destruction of any nuclear warheads removed from active service.

Irreversibility on the agenda

In March 1997, at a summit meeting in Helsinki (with START II having been ratified by the US but not by Russia in the interim), Yeltsin and the then US President Bill Clinton issued a landmark 'Joint Statement on Parameters of Future Reductions in Nuclear Forces' declaring that as soon as START II entered into force, their two countries would 'immediately' begin negotiations on a START III agreement, which was to include, *inter alia*:

- The reduction, by the end of 2007, of strategic warhead numbers down to aggregate levels of 2,000–2,500 apiece;
- 'Measures relating to the transparency of strategic nuclear warhead inventories and the destruction of nuclear warheads and any other technical and organisational measures, *to promote the irreversibility of deep reductions* including prevention of a rapid increase in the number of warheads;'
- 'Resolving issues related to the goal of making the current START treaties unlimited in duration;' and
- The deactivation of all strategic nuclear delivery vehicles set for elimination under START II by removal of their warheads or by the taking of 'other jointly agreed steps.'[81]

77 National Academy of Sciences, *Monitoring Nuclear Weapons and Nuclear-Explosive Materials*, 24.

78 Ibid.

79 Ibid.

80 Goldblat, *Arms Control*, 72.

81 US-Russian Joint Statement on Parameters on Future Reductions in Nuclear Forces, March 1997.

The presidents also agreed, their statement said, that 'in the context of START III negotiations' their experts would 'explore, as separate issues, possible measures relating to nuclear long-range sea-launched cruise missiles and tactical nuclear systems', including 'appropriate confidence-building and transparency measures.' Furthermore, they agreed also to 'consider the issues related to transparency in nuclear materials.'[82]

There is, it should be noted, a slight ambiguity in the 1997 statement by the two presidents. To promote the 'irreversibility of deep reductions', START III was to include measures 'relating to the transparency of strategic nuclear warhead inventories and the destruction of nuclear warheads', the statement said. But whether that meant that transparency measures would relate to inventories *and* warhead destruction, or whether those two were separate (i.e. the statement meant that transparency would apply to inventories, with the destruction of warheads being called for as another matter altogether) is unclear. The quote seems to suggest that transparency measures would apply to both, which fits with the reality that dismantlement operations do take place in both countries—but that is only one possible interpretation.

Whether or not it is done with verification by outside parties, the dismantlement of a state's nuclear warheads—i.e. the separation of a warhead's fissile materials from its nuclear 'physics package'—has been identified elsewhere in this report as the minimum act that would constitute 'disarmament' (using this report's understanding of disarmament as the end state not the process), and so represent the first, and lowest, level of irreversibility. Thus, the ambiguity in the 1997 statement may or may not be critical. Consider that: if it relates to the verification of dismantlement operations, then the significance would be less—since dismantlement already takes place. However, if this statement is understood to mean that 'measures . . . relating to the destruction of nuclear warheads' would be looked into, then the scope of possibilities widens substantially. How many warheads, for instance? The statement might be taken to mean the destruction of *all* nuclear warheads. Which may seem unlikely, but who in the early 1980s would have anticipated that Reagan and Gorbachev would have gone so far as to seriously discuss the elimination of all nuclear weapons at the Reykjavik summit of 1986?

While perhaps the most significant, Helsinki was not the first occasion that Presidents Clinton and Yeltsin had raised the irreversibility issue—or, indeed, the transparency one. In January 1994, the two leaders agreed on the goal of ensuring the 'transparency and irreversibility' of the nuclear arms reduction process, and in May of that year a joint working group on 'Safeguards, Transparency and Irreversibility' was established.[83] Here again, the close rhetorical link between the two—a trend that has continued in policy statements to this day—is evident.

In September 1994, the US and Russia issued a 'Joint Statement on Strategic Stability and Nuclear Stability' declaring their intention to: 'Direct their joint working group on nuclear safeguards, transparency and irreversibility to pursue by March 1995 further measures to improve confidence in and increase the transparency and irreversibility of the process of reducing nuclear weapons.'[84] What became of those efforts is not well documented, but in May 1995, Clinton and Yeltsin then issued a further 'Joint Statement on the Transparency and Irreversibility of the Process of Reducing Nuclear Weapons' expressing 'the desire of the United States of America and the Russian Federation to establish as soon as possible concrete arrangements for enhancing transparency and irreversibility of the process of nuclear arms reduction.'[85]

In their 1995 statement, the presidents declared that no newly-produced fissile material, no fissile material from or within their civil nuclear programmes, and no fissile materials from nuclear weapons being

82 Ibid.

83 *Transparency and Verification Options*, US Department of Energy, 1997, 21.

84 US-Russian *Joint Statement On Strategic Stability And Nuclear Security By The Presidents Of The United States And Russia*, September 1994.

85 US-Russian *Joint Statement on the Transparency and Irreversibility of the Process of Reducing Nuclear Weapons*, May 1995.

eliminated and excess to national security needs would be used to manufacture nuclear weapons. What's more, according to the statement, the two parties would strive to conclude, as soon as possible, agreements to increase the transparency and irreversibility of nuclear arms reductions. These agreements were to include: provisions to regularly exchange detailed information on aggregate stockpiles of nuclear warheads and fissile materials; cooperative arrangements for reciprocal monitoring at the storage facilities of fissile materials removed from warheads and declared to be in excess of national security requirements (in order 'to help confirm the irreversibility of the process of reducing nuclear weapons'); and unspecified other cooperative measures, 'as necessary to enhance confidence in the reciprocal declarations of fissile material stockpiles.'[86]

The statement also noted that the two countries would 'examine and seek to define further measures to increase the transparency and irreversibility of the process of reducing nuclear weapons, including intergovernmental arrangements to extend cooperation to further phases of the process of eliminating nuclear weapons declared excess to national security requirements as a result of nuclear arms reduction.' And the two presidents 'urged progress in implementing current agreements affecting the irreversibility' of nuclear arms reductions, including, specifically, an agreement they reached in June 1994 on the shutting down of plutonium production reactors and ceasing the use of newly-produced plutonium in nuclear weapons. The US and Russia would seek to conclude a bilateral agreement for cooperation, one that would enable the exchange of information necessary to implement the aforementioned arrangements, 'in the shortest possible time', said the statement.[87]

In September 1997, the US Secretary of State Madeleine Albright and Russian Foreign Minister Yevgeny Primakov signed a protocol codifying the commitments made by Clinton and Yeltsin earlier that year in Helsinki. In an exchange of letters, Albright and Primakov also formally agreed that once START II entered into force, the US and Russia would deactivate, by 31 December 2003, all strategic nuclear delivery vehicles due to be eliminated under the accord 'by removing their re-entry vehicles or taking other jointly agreed steps.' At the same time, the US and Russia, along with Belarus, Kazakhstan and Ukraine, signed a memorandum of understanding designating Russia, Belarus, Kazakhstan and Ukraine as successor states to the Soviet Union for the purposes of the ABM treaty. The five states also signed agreements clarifying the demarcation between strategic missile defences (limited by the ABM treaty) and theatre missile defences (unaffected by it).[88]

But START II never made it into force. Russia approved the treaty and its extension protocol in April 2000 but the Russian resolution of ratification complicated matters by linking the exchange of instruments of ratification—the final step needed to bring the treaty into force—to US Senate approval of the 1997 ABM agreements. But Republican opposition to those agreements, and to the ABM treaty itself even, made sure that never happened. The US gave its six-month notice of withdrawal from the ABM treaty in December 2001, under the Republican leadership of President George W. Bush, with withdrawal taking effect in June of the following year.[89]

SORT

In general, it was President George W. Bush's opinion that detailed and complex formal treaties placed too many constraints on US military flexibility and that in the context of a post-Cold War, ostensibly non-

86 Ibid.

87 Ibid.

88 Philipp C. Bleek, *Russia Ratifies START II, Extension Protocol; ABM-Related Agreements Also Approved,* Arms Control Today, May 2000.

89 Ibid.

adversarial relationship with Russia, there was little need for them anyway. Bush, accordingly, initially proposed strategic nuclear arms reductions by way of informal unilateral actions—down to whatever level each side deemed appropriate.[90]

In November 2001, President Bush announced that he would reduce the number of 'operationally deployed' warheads on US strategic delivery systems to between 1,700 and 2,200 over a period of ten years. The Bush administration indicated that it would not eliminate many of the warheads removed from deployment but hold them in reserve (so that they could potentially be returned to service in the future), and that it would pursue its reductions unilaterally, regardless of Russian reciprocity.

At the insistence of Russian President Vladimir Putin, however, Bush ultimately agreed to a formal accord—the Strategic Offensive Reductions Treaty, or SORT—that was signed in Moscow in May 2002, just weeks before the end of US involvement with the ABM treaty. SORT, better known as the Moscow Treaty, called on each party to reduce and limit their number of strategic nuclear warheads to between 1,700 and 2,200 by the end of 2012.[91]

As the US article-by-article analysis of the treaty notes, significantly, the limits of the Moscow Treaty 'relate solely to the number of each party's strategic nuclear warheads.' SORT, which has been in force since June 2003, neither limits the number of US or Russian ICBMs, ICBM launchers, SLBMs, SLBM launchers or heavy bombers.[92] As the NAS have written: 'By agreeing to reductions in operationally deployed strategic offensive nuclear weapons, the Moscow Treaty makes nuclear weapons—as distinct from delivery systems and launchers—the critical security consideration.'[93] That said, the treaty does not address either those strategic weapons kept in reserve or non-strategic weapons, whether deployed or not.

The reductions called for by the Moscow Treaty are similar to those envisioned for START III—both in numerical terms and in the fact that they relate directly to warheads and not delivery vehicles—but the treaty differs from past agreements, planned and actual, in many other respects, and not just the fact that it leaves delivery vehicles entirely to one side. For one, SORT contains no verification mechanisms of its own, falling back on NTM and the monitoring activities allowed under START I—which expired in December 2009. And for another, the treaty includes no counting rules or definitions identifying which warheads were to count under its limit, effectively allowing each party to determine for itself which warheads were applicable. Russia reportedly sought to incorporate START-style counting rules and elimination procedures into the treaty, in order to complicate US efforts to restore warheads to deployed delivery vehicles. As Woolf has noted, that kind of approach would have provided 'a measure of predictability and irreversibility in the reductions.'[94] But the Bush administration resisted proposals to eliminate either excess warheads or delivery vehicles, favouring a state of affairs that would allow for flexibility in the future.

From an irreversibility point of view, SORT—the first US-Russian nuclear arms accord since the 13 practical steps of 2000 NPT review conference, wherein, of course, irreversibility was explicitly mentioned—left much to be desired. Not only did it not require the elimination of delivery vehicles (much less for their elimination to be conducted in a verifiable manner) as was the case under START I, but nor did it require any warhead dismantlement or disposition of fissile materials. In terms of irreversibility, one can therefore make the argument that the Moscow Treaty represented a step back.

90 National Academy of Sciences, *Monitoring Nuclear Weapons and Nuclear-Explosive Materials*, 26.

91 Moscow Treaty article-by-article analysis: http://www.dod.gov/acq/acic/treaties/sort/sort_axa.htm (accessed 21 November 2010).

92 Ibid.

93 National Academy of Sciences, *Monitoring Nuclear Weapons and Nuclear-Explosive Materials*, 26.

94 Amy F. Woolf, 'Nuclear Arms Control: The US-Russian Agenda', Congressional Research Service Issue Brief for Congress, updated 3 January 2006, 9.

A 'New START'

Efforts to negotiate a replacement for START I began in earnest in April 2009, with an agreement between US President Barack Obama and his Russian counterpart, Dmitry Medvedev, on the need for further verifiable reductions in strategic nuclear arms. In July 2009, the two presidents signed a memorandum calling for limits 'in the range of 500–1,100 for strategic delivery vehicles, and in the range of 1,500–1,675 for their associated warheads.' Their statement also noted that a new treaty would include: 'Provisions on data exchanges, notifications, eliminations, inspections and verification procedures, as well as confidence-building and transparency measures, as adapted, simplified, and made less costly, as appropriate,' in comparison with the original START.

The 'New START' treaty, as the deal came to be known, was eventually signed in April 2010, some months after the expiration of START I. It calls on each party to ensure that seven years after entry into force they possess no more than: (a) 700 deployed ICBMs, SLBMs and heavy bombers; (b) 1,550 warheads on deployed ICBMs, SLBMs and nuclear warheads counted for heavy bombers; (c) 800 deployed and non-deployed ICBM launchers, SLBM launchers and heavy bombers.[95]

In terms of warhead counting rules, New START differs significantly from START I by counting the actual number of devices deployed on ICBMs and SLBMs (each heavy bomber is counted as one warhead regardless of the number, which may be significantly more, deployed on them). Whereas ICBM and SLBM counts under START I were conducted according to mutually agreed attributed amounts for each type of missile, Article III of the New START treaty states that: 'For ICBMs and SLBMs, the number of warheads shall be the number of re-entry vehicles emplaced on deployed ICBMs and deployed SLBMs.' Under New START, missiles will not count as if they carried the maximum number of warheads tested on that particular type of missile. Rather, each missile is to count according to the number warheads actually deployed on it, which can of course change over the life-span of the treaty. Verification of these numbers will be conducted by way of random inspections (ten per year)—a measure designed to *deter* the deployment of additional warheads by creating the possibility that a missile with extra warheads might be selected for inspection.[96]

Overall, New START includes a detailed verification regime that combines many of the elements of the original START I regime with new ones tailored for its own specific purposes. Under New START, an initial database will be created with 45 days of the treaty's entry into force that is to include the 'unique identifier' of each deployed and non-deployed ICBM, SLBM and heavy bomber and their locations. This database—which must be fully updated every six months—will also specify the total number of deployed warheads each country has, by type of missile, and the aggregate number of warheads deployed on all missiles at each base. Most changes to the database require notifications within five days. When a new missile or heavy bomber is deployed, or when a deployed missile or launcher is moved from one base to another, or when a missile or bomber changes from a deployed to a non-deployed status (or vice versa) the other party must be notified and the database updated accordingly.[97]

On-site inspections will offer access to additional data on missiles and bombers. When an ICBM, SLBM or air base is inspected (which may take place up to ten times each year, as noted above), in what the treaty labels 'Type One' inspections, the inspectors will be told and shown where each missile is, and told how many warheads are deployed on it. The inspectors may then pick one missile and be shown

95 Senate Foreign Relations Committee 'Executive Report 111-06: Treaty with Russia on Measures for Further Reduction and Limitation of Strategic Offensive Arms', 2.

96 *Treaty Between The United States Of America And The Russian Federation On Measures For The Further Reduction And Limitation Of Strategic Offensive Arms*, 2010.

97 Senate Foreign Relations Committee 'Executive Report 111-06', 26.

how many warheads that missile is carrying.[98] The inspected party can cover the re-entry vehicles to protect information not related to the number of warheads, but they must use individual covers for each re-entry vehicle, so that the number of warheads deployed on the missile is evident to the inspectors. As has become customary, though, nothing in New START calls for warheads removed from active service to be eliminated—much less verifiably so.

Looking at New START through an irreversibility prism, the similarities with START I, in terms of the elimination of delivery vehicles, are (unsurprisingly) the most apparent. And so, then, are the same faults—most notably the lack of any requirements for warheads to be dismantled. It may be the case that under New START both the US and Russia do in fact dismantle all warheads removed from service, and destroy—or slate for destruction—the fissile material components of each and every one. And if that were extended to cover all warheads in their possession then it would be possible to begin talking of disarmament irreversibility. But START I establishes no procedures for the dismantlement of warheads, as it and treaties before it have done for delivery vehicles, and while it does mark a significant departure from the system of counting 'attributed' warheads, it is only through the actual destruction of warheads that disarmament can realistically be achieved to even the first level of irreversibility outlined in this report.

Overall assessment

What this examination of past arms treaties reveals, perhaps most starkly of all, is the lack of serious consideration—and sometimes, such as in the case of SORT, the outright avoidance—of irreversibility, even though all of the above treaties still leave (or would have left) each side in possession of many thousands of deployed nuclear weapons. That no treaty between the two powers has required the actual dismantlement of nuclear warheads, nor the destruction or stuffing of their fissile pits, presents stark evidence of the vast distance yet to be travelled on the road to eventual nuclear disarmament.

In analysing these agreements, an underlying tension between this annex and the subject of the report has been the difference between nuclear arms *reduction* and *limitation* agreements, as these are, and nuclear *disarmament* as conceived of in this report. Nonetheless, the importance of these US-Russian cases is not so much their direct applicability to the subject of irreversible nuclear disarmament, but their usefulness in pointing toward various aspects that could and would contribute to irreversibility in a disarmament scenario.

Dismantlement (whether verified or not) is perhaps the most obvious aspect, given the relative ineffectiveness of controls on delivery vehicles for the achievement of irreversible dismantlement. Following dismantlement, another aspect would be an extension of the various agreements governing the disposition of HEU and plutonium deemed in excess of defence needs. If all warheads in a state were dismantled, all fissile material could be considered to be in excess of defence needs—*unless a state was hedging for the future*. If a state wanted to retain a reasonably fast capacity to rearm in the future, keeping stocks of weapons-usable fissile materials would ease the path to rearmament significantly. If those fissile materials were in the form of intact pits then the path to rearmament would be shorter still.

98 Senate Foreign Relations Committee 'Executive Report 111-06', 27. This is different from re-entry vehicle inspections under START I, during which the only requirement was to demonstrate that the missile did not have more warheads than the number attributed to it in the START I database.

Annex II: North Korean nuclear 'freezing' and 'disablement'

North Korea represents a particularly interesting case in the study of disarmament irreversibility. Despite the various agreements and physical measures aimed at rolling back North Korea's nuclear capabilities, no durable or long-lasting progress has yet been achieved. The Democratic People's Republic of Korea (or DPRK), as the North is more properly known, has managed in more than one instance to reverse steps taken toward the dismantlement of its nuclear weapons programme, with significant consequences. The DPRK has twice tested nuclear devices—first in 2006, then in 2009—and the impasse over the DPRK's nuclear programme continues.

This annex provides a historical overview of international efforts to influence North Korean nuclear activities. It highlights in particular two periods when measures were applied to rein in North Korean nuclear advances and move toward the eventual dismantlement of its nuclear weapons complex. The first stretches from 1994 until 2002, during which the North Korean programme was subject to measures that constituted a 'freeze' of its nuclear activities. The second spanned from 2007 until 2009 and saw the DPRK and the US implement a 'disablement' action plan designed to ensure a more difficult restart of the programme.

North Korea's initial declaration—and problems therein

Under Russian pressure, the DPRK joined the NPT in December 1985 but it was not until January 1992 that North Korea concluded a nuclear safeguards agreement with the IAEA. In May of that year, the DPRK provided the IAEA with its initial declaration of nuclear material. Subsequent IAEA inspections at North Korea's Yongbyon nuclear complex, however, highlighted a number of discrepancies in this initial declaration—principally related to the amount of plutonium that North Korea claimed to have produced through the reprocessing of spent nuclear fuel.

As a result, in late 1992 and early 1993 the IAEA asked North Korea several times for access to two suspect waste sites, the analysis of which would have assisted in verifying the amount of past plutonium production in North Korea. But the DPRK refused. As a result, in February 1993, the IAEA requested 'special inspections' of the two sites, a call affirmed by the IAEA's Board of Governors later in the month. In response, North Korea gave its three-month notice of withdrawal from the NPT, although it abandoned this decision shortly before the withdrawal was due to come into effect. [99]

To complicate matters further, in May 1994, the DPRK informed the Agency that it had started unloading the 5MWe reactor that it has at Yongbyon without putting in place a number of requested safeguards measures that would have helped the IAEA to verify the operational history of the reactor. In June 1994, the IAEA's then director-general, Hans Blix, wrote to the UN Security Council stating that the IAEA's ability to determine past diversion of plutonium had been 'seriously eroded' by the DPRK's actions at the 5MWe reactor. He noted further that North Korea's refusal to accept special inspections of the two suspect waste sites and its unloading of the reactor without the IAEA's requested verification measures in place meant that the Agency was unable to provide an assurance as to the non-diversion of nuclear material in the DPRK.[100]

A breakthrough was made in June 1994, however, when North Korea agreed to 'freeze' its plutonium production nuclear programme. In return, the US suspended a campaign to impose UN sanctions on the country and announced that it would resume bilateral negotiations.[101]

99 IAEA DPRK fact sheet: https://iaea.org/NewsCenter/Focus/IaeaDprk/fact_sheet_may2003.shtml (accessed 27 November 2010).

100 David Albright and Holly Higgins, 'Looking Back', 23, in *Solving the North Korean Nuclear Puzzle*, ed. David Albright and Kevin O'Neill, ISIS, 2000.

101 Ibid.

The 1994 'Agreed Framework'

In October 1994, after several months of negotiations, this freeze was formalised into the 'Agreed Framework between the United States of America and the Democratic People's Republic of Korea', or simply the Agreed Framework. This agreement represents the first major effort to roll back the North Korean nuclear programme.

Under the Agreed Framework, both sides were to 'cooperate to replace the DPRK's graphite-moderated reactors and related facilities with light-water reactor (LWR) power plants.' The US was to 'make arrangements for the provision to the DPRK of an LWR project with a total generating capacity of approximately 2,000 MW(e) by a target date of 2003.' Under the agreement, the US would lead an international consortium to finance and supply the LWR project to be provided to the DPRK,' and to make 'best efforts' to conclude a supply contract with North Korea within six months.[102]

Pending completion of the first LWR unit, the US, representing the consortium, was to make arrangements to provide alternative energy to North Korea in the form of heavy fuel oil for heating and electricity production. The Framework stated that the freeze on the DPRK's graphite-moderated reactors and related facilities was to be 'fully implemented' within one month. During this one-month period, and thereafter, the IAEA was to be allowed to monitor the freeze, and the DPRK was to provide 'full cooperation with the IAEA for this purpose.'[103]

This freeze, however, was meant only as an interim step. The ultimate objective of the agreement was to dismantle critical DPRK nuclear facilities in exchange for a package of inducements, including more proliferation-resistant reactors, fuel supplies and improved political and economic relations with the US and its regional allies.

Thus, the Framework stated that the DPRK would not only freeze its graphite-moderated reactors and the facilities related to them, but that it would 'eventually dismantle' these reactors and facilities also. 'Dismantlement of the DPRK's graphite-moderated reactors and related facilities will be completed when the LWR project is completed,' said the deal. At the stage when a 'significant portion of the LWR project is completed, but before delivery of key nuclear components,' the DPRK was to 'come into full compliance with its safeguards agreement with the IAEA . . . including taking all steps that may be deemed necessary by the IAEA, following consultations with the Agency with regard to verifying the accuracy and completeness of the DPRK's initial report on all nuclear material in the DPRK.'[104]

The Agreed Framework deal also noted that the US and North Korea were to 'cooperate in finding a method to store safely' the spent fuel from the 5MWe reactor during construction of the LWR project, 'and to dispose of the fuel in a safe manner that does not involve reprocessing in the DPRK.'[105] As David Albright and Holly Higgins have noted, US officials interpreted the call to 'store safely' the spent fuel as meaning that the DPRK would ultimately send that fuel to another country.[106]

The Agreed Framework falls apart

While the Agreed Framework ultimately kept the North Korean plutonium programme frozen for almost a decade, not to mention the fact that it enabled the 'canning' of 8,000 spent fuel rods in the Yongbyon

102 *Agreed Framework between the United States of America and the Democratic People's Republic of Korea*, 1994.

103 Ibid.

104 Ibid.

105 Ibid.

106 David Albright and Holly Higgins, 'Looking Back', 27.

spent fuel pond (a process certified complete by US President Bill Clinton in June 2000), implementation of the agreement was far from smooth. Repeated delays over the construction of the two light-water plants saw their estimated completion date pushed back and back, to 2010 according to a North Korean estimate in 2000, and negotiations between the DPRK and the IAEA over the preservation of information—to facilitate verification of the DPRK's initial declaration—made slow headway.[107]

Shortly after President George W. Bush took office in January 2001, his administration declared its intention to undertake a full review of US policy toward North Korea. That review, completed in June 2001, concluded that the US would seek serious discussions with the DPRK on a 'broad agenda.' This included —in addition to 'improved implementation' of the Agreed Framework—verifiable constraints on North Korea's missile program, a ban on missile exports, and a less-threatening North Korean conventional military posture.'[108]

Following the 9/11 terrorist attacks of September 2001, President Bush listed North Korea as one of the three 'axis of evil' states, along with Iran and Iraq, and in October 2002 his administration riled North Korea by accusing the DPRK of admitting to the possession of a secret uranium enrichment programme.[109]

In November 2002, the IAEA Board of Governors adopted a resolution calling on North Korea to 'clarify' its reported enrichment activities, which the DPRK by now denied having.[110] Heavy fuel oil shipments to North Korea were also suspended. In December 2002, North Korea sent a letter to the IAEA announcing that it was restarting its 5MWe reactor and reopening other facilities covered by the Agreed Framework. The letter requested that the Agency remove all seals and monitoring equipment from nuclear facilities in the DPRK. Inspectors from the Agency left on 31 December 2002 after North Korea ordered them out.

In early January 2003, the IAEA Board of Governors adopted a resolution condemning the DPRK's decision to 'remove and impede the functioning of containment and surveillance equipment at its nuclear facilities,' and the expulsion of IAEA inspectors. The resolution called on North Korea to re-establish monitoring and containment equipment, to allow inspectors back in, and (as before) to clarify its reported uranium enrichment activities, or, the Board warned, 'the DPRK would be in further non-compliance with its safeguards agreement.'[111] The North Korean response was to announce, on 10 January 2003, that it was withdrawing from the NPT with near-immediate effect, arguing—somewhat spuriously—that it had already served its three-month notice period in the early 1990s.[112]

In February 2003, the IAEA Board agreed to refer the North Korean matter to the United Nations.[113] That month, US officials confirmed that the DPRK had restarted its 5MWe reactor at Yongbyon. US intelligence also detected activities around the Yongbyon reprocessing plant to indicate that North Korea was likely reprocessing the 8,000 spent fuel rods that had been in the spent fuel pond. Indeed, in early October 2003, a spokesman for the North Korean foreign ministry announced that the DPRK had successfully

107 See David Albright and Holly Higgins, 'Status Report' in, *Solving the North Korean Nuclear Puzzle*, ed. in David Albright and Kevin O'Neill, ISIS, 2000, 31–42.

108 On US policy changes toward North Korea, see Michael J. Mazarr, 'The long road to Pyongyang: a case study in policy making without direction' *Foreign Affairs*, September/October 2007.

109 Congressional Research Service, 'North Korea: A Chronology of Events, October 2002-December 2004', CRS Report for Congress, 24 January 2005.

110 IAEA Media Advisory, 29 November 2002: http://www.iaea.org/NewsCenter/MediaAdvisory/2002/med-advise_033.shtml (accessed 27 November 2010).

111 IAEA Media Advisory, 6 January 2003: http://www.iaea.org/NewsCenter/MediaAdvisory/2003/med-advise_004.shtml (accessed 27 November 2010).

112 Text of North Korea's Statement on NPT Withdrawal, 10 January 2003: http://www.atomicarchive.com/Docs/Deterrence/DPRKNPTstatement.shtml (accessed 27 November 2010).

113 IAEA Media Advisory, 12 February 2003: http://www.iaea.org/newscenter/mediaadvisory/2003/med-advise_048.shtml (accessed 27 November 2010).

finished reprocessing the 8,000 fuel rods and in January 2004, a delegation of invited US experts confirmed that the canisters in the pond were empty.[114]

The six-party talks and the Bush administration's 'CVID' approach

As James Kelly, the US assistant secretary for East Asian and Pacific affairs, told the US Senate Foreign Relations Committee in July 2004, the Bush administration adhered to 'two basic principles' to resolve the DPRK 'threat'. First, Kelly said, the US sought the 'complete, verifiable and irreversible dismantlement' of the DPRK's nuclear programmes—a demand often shortened to 'CVID'. And second, because the DPRK's nuclear programmes threaten both its neighbours and the 'integrity of the global nuclear non-proliferation regime,' Kelly said, the US sought to engage with North Korea on a multilateral basis.[115]

In April 2003, the US took part in three-way talks on North Korea's nuclear efforts with the DPRK and China. (There, Kelly told the Senate committee, 'the North Koreans pulled me aside to say that they have nuclear weapons, will not dismantle them, and might transfer or demonstrate them.') The forum was subsequently expanded to include Japan, Russia, South Korea and the first round of 'six-party talks' were held in August 2003, followed by a second in February of the following year.[116]

In June 2004, at the third round of talks, the US presented North Korea with a detailed proposal for resolving the nuclear crisis, a proposal developed in 'close coordination' with Japan and South Korea according to Kelly, and underpinned by the CVID concept. As Kelly explained to the committee:

> Under the US proposal, the DPRK would, as a first step, commit to dismantle all of its nuclear programmes. The parties would then reach agreement on a detailed implementation plan requiring, at a minimum, the supervised disabling, dismantlement and elimination of all nuclear-related facilities and materials; the removal of all nuclear weapons and weapons components, centrifuge and other nuclear parts, fissile material and fuel rods; and a long-term monitoring programme.

The US envisaged a 'short initial preparatory period, of perhaps three months duration,' said Kelly, in order to prepare for the dismantlement and removal of the DPRK's nuclear programmes. During that initial period, the DPRK was to:

- Provide a complete listing of all its nuclear activities, and cease them all;
- Permit the securing of all fissile material and the monitoring of all fuel rods; and,
- Permit the 'publicly-disclosed and observable disablement' of all nuclear weapons/weapons components and key centrifuge parts.

These actions by the DPRK would be subject to international verification, Kelly explained, although exact verification arrangements and organisations were not specified.

Under the US proposal, 'as the DPRK carried out its commitments, the other parties would take some corresponding steps,' Kelly said. 'These would be provisional or temporary in nature and would only yield lasting benefits to the DPRK after the dismantlement of its nuclear programmes had been completed.' According to Kelly, 'upon agreement of the overall approach, including a DPRK agreement to dismantle all nuclear programmes in a permanent, thorough and transparent manner subject to effective verification,

114 Nuclear Threat Initiative 'North Korea Profile': http://www.nti.org/e_research/profiles/NK/Nuclear/index.html.

115 Statement of James A. Kelly to the Senate Foreign Relations Committee, 'Dealing With North Korea's Nuclear Programs', 15 July 2004.

116 Ibid.

non-US parties would provide heavy fuel oil to the DPRK.' Upon acceptance of the North Korean declaration, the parties would: provide provisional multilateral security assurances to the DPRK; begin a study to determine the energy requirements of the DPRK and how to meet them by non-nuclear means; begin a discussion of the steps necessary to lift remaining economic sanctions on the DPRK, and on the steps necessary to remove North Korea from the US List of State Sponsors of Terrorism.[117]

For their part, the DPRK put forward a proposal of their own, one based on a 'freeze for rewards' system, by which the DPRK would agree to freeze all facilities related to nuclear weapons and refrain from all nuclear weapons-related activities in return for rewards such as energy assistance, the lifting of sanctions and removal from the US list of terrorist sponsors. According to Kelly, the DPRK delegation to the talks 'clearly identified the 5MWe reactor as a nuclear weapons facility,' and acknowledged, furthermore, that 'most of their nuclear programmes' were in fact weapons-related. Under the DPRK proposal, however, actual dismantlement would only come, as Kelly put it, 'further down the line,' and there was no mention of uranium enrichment, which he stated would be a 'critical' factor in any deal.[118]

Landmark statement issued in 2005

On 19 September 2005, at the conclusion of the fourth round of six-party talks, the parties issued a landmark Joint Statement in which the DPRK committed 'to abandoning all nuclear weapons and existing nuclear programmes and returning, at an early date, to the Treaty on the Non-Proliferation of Nuclear Weapons and to IAEA safeguards.' In return, the other parties to the talks 'agreed to discuss, at an appropriate time,' the provision of light-water reactor technology to the DPRK. In the statement, the US also 'affirmed that it had no nuclear weapons on the Korean Peninsula' and 'no intention to attack or invade the DPRK with nuclear or conventional weapons.' The statement, which reaffirmed the goal of the six-party process as the 'verifiable denuclearisation of the Korean Peninsula in a peaceful manner,' also called for the 1992 joint denuclearisation declaration to be 'observed and implemented.'[119]

While undoubtedly significant, the statement was far from perfect—or even complete. As David Albright and Corey Hinderstein have argued, it failed to address many key disputed issues, such as the timing of dismantlement and rewards, how dismantlement was to be verified, the scope of the programmes to be abandoned, or the future of nuclear power in North Korea. (These issues were to be addressed at subsequent rounds of talks.)[120]

But talks faltered shortly after, and on 9 October 2006, North Korea conducted its first explosive nuclear test.[121] That saw the UN Security Council promptly adopt Resolution 1718, condemning the act, enacting a range of multilateral sanctions against North Korea and calling on the DPRK to abandon 'all nuclear weapons and existing nuclear programmes', as well as all other weapons of mass destruction and ballistic missile capabilities, in a 'complete, verifiable and irreversible manner.'[122]

117 Ibid.

118 Ibid.

119 Full text of 2005 six-party joint statement: http://www.chinadaily.com.cn/english/doc/2005-09/19/content_479150_2.htm.

120 David Albright and Corey Hinderstein, *Dismantling the DPRK's Nuclear Weapons Program: A Practicable, Verifiable Plan of Action,* United States Institute of Peace, 2006, 2.

121 Arms Control Association factsheet on North Korea: http://www.armscontrol.org/factsheets/northkoreaprofile (accessed 27 November 2010).

122 United Nations Security Council Resolution 1718, 14 October 2006.

The 2007 'disablement' plan

In an apparent breakthrough, on 13 February 2007 the six parties agreed to a set of 'Initial Actions for the Implementation of the Joint Statement' of September 2005.[123] According to this Initial Actions plan, the six parties 'reaffirmed their common goal and will to achieve early denuclearisation of the Korean Peninsula in a peaceful manner and reiterated that they would earnestly fulfil their commitments in the Joint Statement.' More importantly, they 'agreed to take coordinated steps to implement the Joint Statement in a phased manner in line with the principle of "action for action".'[124]

In the 'initial phase,' the DPRK was to 'shut down and seal for the purpose of eventual abandonment the Yongbyon nuclear facility, including the reprocessing facility', and invite back IAEA personnel 'to conduct all necessary monitoring and verification as agreed between the IAEA and the DPRK.' The DPRK was also to discuss with other parties a detailed list of all its nuclear programmes. Meanwhile, the DPRK and the US would 'start bilateral talks aimed at resolving bilateral issues and moving towards full diplomatic relations.' The US was also to begin the process of removing North Korea from its list of states sponsoring terrorism.[125]

Once the initial actions were implemented, the six parties were to hold a ministerial meeting 'to confirm implementation of the Joint Statement and explore ways and means for promoting security cooperation on Northeast Asia.' According to the plan: 'During the period of the Initial Actions phase and the next phase—which includes provision by the DPRK of a complete declaration of all nuclear programmes and disablement of all existing nuclear facilities, including graphite-moderated reactors and reprocessing plant—economic, energy and humanitarian assistance up to the equivalent of 1 million tons of heavy fuel oil (HFO), including the initial shipment equivalent to 50,000 tons of HFO, will be provided to the DPRK.'[126]

The concept of disablement arose as a result of the speed with which North Korea restarted its 5MWe reactor and reprocessing facility following the collapse of the Agreed Framework. The United States was to lead disablement activities and provide the initial funding for them.

Speaking to the press on 3 October 2007, the lead US negotiator at the six-party talks, Christopher Hill, declared that disablement essentially meant taking steps 'to make it difficult to restart a nuclear programme.' Shutting down and sealing a reactor involved a certain degree of 'political disablement' said Hill; that is, that North Korea would have to 'void a six-party deal, kick out IAEA inspectors, unseal the facility and turn it back on.' But, he said, what the US wanted, 'as a sort of added confidence-building measure', was to go beyond political disablement to 'actual physical disablement.'[127]

As defined by David Albright and Paul Brannan in a 2007 paper, the disablement of a facility refers to 'a deliberate, mutually-agreed action or set of actions taken to make it relatively more difficult and time-consuming to restart a facility after it is shut down.' Disablement actions go beyond simply shutting down, sealing and monitoring a facility, they note. 'Although disablement steps can be reversed and the facility restarted, it would take an extended period of time to do so.'[128]

By September 2007, the US seemed to have dropped permanent disablement as a short-term goal, with Hill saying on 25 September that the US was seeking a set of disablement steps that it would take around

123 Joint Statement: Six-Party Talks on N. Korea Disarmament, February 13, 2007, published in, http://www.washingtonpost.com/wp-dyn/content/article/2007/02/13/AR2007021300508_pf.html.

124 Ibid.

125 Ibid.

126 Ibid.

127 On-The-Record Briefing: Assistant Secretary of State for East Asian and Pacific Affairs and Head of the US Delegation to the Six-Party Talks Christopher R. Hill, http://merln.ndu.edu/archivepdf/northkorea/state/93234.pdf.

128 David Albright and Paul Brannan, *Disabling DPRK Nuclear Facilities*, United States Institute of Peace, 2007, 5.

a year to reverse, a time-frame he referred to again in his comments of 3 October. In its physical as opposed to political form, disablement therefore lies somewhere between freezing the operation of a facility and the dismantling of that facility altogether.

Agreed disablement steps

Ultimately, following negotiations between North Korea and members of the six-party process, 11 disablement steps were agreed: three at the 5MWe reactor; four at the reprocessing facility; and four at the fuel fabrication facility. As recorded by the US Congressional Research Service, those steps were as follows:[129]

	Step	**Facility**	**Status**
1	Discharge of 8,000 spent-fuel rods to the spent-fuel pool	5MWe reactor	6,400 completed as of April 2009
2	Removal of control rod drive mechanisms	5MWe reactor	To be done after spent-fuel removal completed
3	Removal of reactor cooling loop and wooden cooling tower interior structure	5MWe reactor	Tower demolished on 26 June 2008
4	Cut cable and remove drive mechanism associated with the receiving hot cell door	Reprocessing facility	Completed
5	Cut two of four steam lines into the reprocessing facility	Reprocessing facility	Completed
6	Removal of drive mechanisms for the fuel cladding shearing and slitting machines	Reprocessing facility	Completed
7	Removal of crane and door actuators that permit spent fuel rods to enter the reprocessing facility	Reprocessing facility	Completed
8	Disablement of fresh fuel rods	Fuel fabrication facility	Not agreed to by North Korea; consultations held in January 2009 with South Korea on possibility of purchase
9	Removal and storage of three uranium ore concentrate dissolver tanks	Fuel fabrication facility	Completed
10	Removal and storage of seven uranium conversion furnaces, including storage of refractory bricks and mortar sand	Fuel fabrication facility	Completed
11	Removal and storage of both metal casting furnaces and vacuum system, and removal and storage of eight machining lathes	Fuel fabrication facility	Completed

The disablement process in North Korea began in early November 2007 and progressed, at varying speeds and with one moderately serious stoppage, until April 2009.[130] By then, eight of the 11 steps had been completed; the most visible—and symbolic—being the destruction of the cooling tower for the 5MWe reactor in June 2008. The most time-consuming (and ultimately unfinished) step was the transfer of fuel rods from the reactor to the cooling pond. By April 2009, some 6,400 of 8,000 rods (i.e. around 80 per cent of the total) had been transferred.[131]

129 Mary Beth Niktin, 'North Korea's Nuclear Weapons', Congressional Research Service, 2009, 11–12.

130 Mary Beth Niktin, 'North Korea's Nuclear Weapons', 13. (The stoppage in question ran from August-October 2008 and resulted from the non-removal of the DPRK from the US State Sponsors of Terrorism List after the submission of the North Korean declaration—a declaration on which trace elements of HEU were found, despite repeated North Korean denials of an enrichment programme—due to ongoing US concerns over verification.)

131 Mary Beth Niktin, 'North Korea's Nuclear Weapons', 13.

How effective were the steps taken?

In assessing the effectiveness of disablement steps taken in the DPRK, it is instructive to consider the reports of Stanford University Professor Siegfried Hecker. Professor Hecker has visited the Yongbyon nuclear complex several times and provided valuable insights on the state of North Korean nuclear facilities. Professor Hecker's visits have at times been the only source of detailed and independent information on North Korean activities, particularly at times when IAEA inspectors were not allowed in.

After visiting the Yongbyon nuclear complex in Febuarary 2008, Hecker concluded that the DPRK had made the decision to permanently shut down plutonium production 'if the United States and the other four parties' in the six-party framework lived up to their 3 October 2007 commitments. He noted that the North Koreans had 'retained a hedge to be able to restart the facilities if the agreement falls through.' Cooperation between US and North Korean teams was reported to have been 'excellent', with a good balance struck 'between doing the job expeditiously and doing it safely.'[132]

As Hecker summarised, and as noted above, on 15 July 2007 the DPRK 'shut down and sealed the key facilities at Yongbyon and allowed IAEA inspectors back to monitor the shut-down.' North Korean workers began to disable those facilities under US technical supervision a few months later. The shut-down had the effect of stopping the production of additional plutonium that the North could use in nuclear bombs, and the subsequent disablement actions were designed to make it more difficult to restart plutonium production in the future.[133]

In the report of his February 2008 visit to Yongbyon, Hecker wrote that his overall assessment was that the disablement steps taken up to that point were 'significant'. But that, as noted above, the North Koreans were retaining a hedge capability to possibly restart production in the future. 'All of the equipment removed as part of the disablement is being stored,' Hecker noted. 'At this point, all actions could be reversed and the facilities restarted.' In terms of timelines, Hecker estimated that: 'With only approximately one quarter of the reactor fuel having been discharged to date (end of February 2008), it may take six to 12 months to restart all facilities. If the reactor fuel discharge is completed and the fresh fuel in storage is disabled or sold, the time for restart would most likely increase to 12 to 18 months.'[134]

In any case, wrote Hecker, no reversal actions could be taken without the knowledge of the US disablement team and IAEA personnel. 'Also, since no maintenance is allowed, the longer the facilities remain disabled, the more difficult it will be for the DPRK to restart them.'[135] In conclusion, Hecker wrote:

> The current six-party process has put within reach permanently shutting down the Yongbyon plutonium production complex. To do so, highest priority must be placed on completing the disablement (discharging the reactor fuel and disabling or selling the existing fresh fuel rods) and proceeding to the dismantlement stage. If this is accomplished, then the DPRK will not be able to make more bombs and, without additional nuclear tests, it will not be able to make better bombs.[136]

132 Siegfried S. Hecker, 'Report of Visit to the Democratic People's Republic of North Korea (DPRK) Pyongyang and the Nuclear Center at Yongbyon, Feb. 12-16 2008', 14 March 2008, 1.

133 Ibid., 3.

134 Ibid., 6.

135 Ibid., 6–7.

136 Ibid., 7.

April 2009, disablement halted

On 14 April 2009, in response to UN condemnation of a North Korean rocket launch (widely suspected of being cover for a long-range ballistic missile test),[137] the DPRK announced that it was withdrawing from the six-party process and would no longer be bound 'to any agreement of the talks'. Accordingly, the North Korean statement said that the DPRK would 'restore to their original state the nuclear facilities which had been disabled according to the agreement of the six-party talks and bring their operation back on a normal track'; and also, that it would 'fully reprocess' the spent fuel rods from its Yongbyon reactor. North Korea also announced that it would 'positively examine' the construction of a light-water reactor and 'boost its nuclear deterrent for self-defence in every way.'[138]

Two days later, the DPRK ejected IAEA and US monitors from the Yongbyon complex. The following month, North Korea conducted its second underground nuclear test explosion, to widespread international outcry and, shortly thereafter, a condemnatory UN Security Council resolution (no. 1874, of 12 June 2009). On 13 June 2009, in a statement responding to the adoption of Resolution 1874, the DPRK stated, firstly, that it would weaponise its plutonium, and secondly, that 'the process of uranium enrichment' would be 'commenced.' Their statement noted that, pursuant to their decision to build a light-water reactor, 'enough success has been made in developing uranium enrichment technology to provide nuclear fuel' to allow experimental procedures to be run.[139]

On 4 September 2009, the DPRK issued a further statement, noting that the reprocessing of spent fuel rods was in its 'final phase' and that extracted plutonium was being weaponised. The September statement also noted, somewhat opaquely, that: 'Experimental uranium enrichment has successfully been conducted to enter into completion phase.'[140]

Post-disablement assessment

On 12 May 2009, around one month after the DPRK's abandonment of the six-party process, Hecker wrote an article on 'The risks of North Korea's nuclear restart' in the *Bulletin of the Atomic Scientists*.[141] As the article noted, prior to its controversial April 2009 rocket launch, North Korea had discharged approximately 6,100 of the 8,000 fuel rods from the 5MWe into the cooling pool, 'but disablement slowed to a crawl of 15 fuel rods/week,' Hecker noted, 'dragging out the projected completion of fuel unloading well into 2011.' What's more, Hecker wrote, progress also stalled on negotiating a protocol to verify past plutonium production because the DPRK refused to allow sampling of the reactor's graphite core, the reprocessing facility, and waste sites. And verification was essential, 'because of the discrepancies between Pyongyang's plutonium declaration and US estimates.' Meanwhile, Hecker reported, no progress had been made on the declaration of weaponisation facilities outside of Yongbyon, the existence of a uranium enrichment program, and the extent and nature of Pyongyang's nuclear exports.'[142]

137 See 'Defiant N Korea launches rocket', BBC News at: http://news.bbc.co.uk/1/hi/7982874.stm (accessed 27 November 2010).

138 'DPRK Foreign Ministry Vehemently Refutes UNSC's "Presidential Statement",' http://www.kcna.co.jp/item/2009/200904/news14/20090414-23ee.html (accessed 27 November 2010). On 29 April 2009, North Korea announced that it would 'make a decision to build a light water reactor power plant and start the technological development for ensuring self-promotion of nuclear fuel as its first process without delay' – see 'UNSC Urged to Retract Anti-DPRK Steps', http://www.kcna.co.jp/item/2009/200904/news29/20090429-14ee.html (accessed 27 November 2010).

139 As reported in: 'DPRK Foreign Ministry Declares Strong Counter- Measures against UNSC's "Resolution 1874",' http://www.kcna.co.jp/item/2009/200906/news13/20090613-10ee.html.

140 Ibid.

141 Siegfried S. Hecker, 'The risks of North Korea's nuclear restart', *Bulletin of the Atomic Scientists* 12 May 2009.

142 Ibid.

As Hecker noted, on 24 April 2009 the DPRK announced that it had already restarted its reprocessing facility:

> This is not surprising because during a previous suspension of disablement actions in September 2008 (as part of a dispute with the Bush administration about not being removed from the list of states sponsoring terrorism), North Korean specialists were able to quickly re-install disabled reprocessing equipment within two to three weeks. After President Bush removed North Korea from the list on October 11, 2008, Pyongyang reciprocated by disabling the equipment once more. Although Yongbyon specialists did not introduce spent fuel into the reprocessing facility at that time, they performed maintenance while conducting flow tests and leak checks, which facilitated restarting the facility now.[143]

With regard to the reactor, once the remaining fuel rods were removed, several steps would need to be taken before the reactor could operate again, Hecker noted. The cooling tower would need to be rebuilt, for one (unless North Korea was willing to construct an alternative cooling system or settle for very low power levels), and the reactor would need fresh fuel. At this time, North Korea did not have enough fuel for a full core for the 5MWe reactor. Some of its fuel stockpile was in forms unsuitable for this reactor and that would require machining in order to fit. To make entirely new fuel rods for the reactor would 'most likely require North Korea to bring the entire fuel fabrication facility back into operation,' Hecker wrote, which would be difficult, because the facility was 'substantially disabled, and some of the facilities had decayed seriously during the 1994–2002 freeze.'[144]

Uranium enrichment activities revealed

In November 2010, after another visit to the Yongbyon nuclear complex, Hecker noted that the 5MWe reactor had not been restarted since it was shut down in 2007. During his visit, he observed that the spent fuel rods had been reprocessed following North Korea's withdrawal from six-party talks in 2009 but that no new fuel had reportedly been processed, 'and the fresh fuel produced prior to 1994 (sufficient for one more reactor core) [was] still in storage [at the fuel fabrication facility].'[145]

Hecker also noted that there appeared to be no activity at the Yongbyon reprocessing facility. Its condition, however, is unknown. Overall, Hecker concluded, the DPRK 'has apparently decided not to make more plutonium or more plutonium bombs for now.' Indeed, converting the metal fuel rod fabrication building to centrifuge uses has made it more difficult to make fuel for the reactor in the future; but, Hecker estimated, the DPRK 'could resume all plutonium operations within approximately six months and make one bomb's worth of plutonium per year for some time to come.'[146]

Notably, while at Yongbyon, Hecker and his colleagues were shown a 25–30MWe experimental light-water reactor 'in the early stages of construction.' Construction had apparently started in late July 2010, and the target date for completion was reportedly 2012, which, Hecker suggested, 'appears much too optimistic.' Most significantly though, Hecker's November 2010 report also revealed the existence of a recently completed, 'modern, small industrial-scale uranium enrichment facility with 2,000 centrifuges . . . said to be producing low-enriched uranium (LEU) destined for fuel for the new reactor.'[147] The centrifuges are located in what used to be the metal fuel rod fabrication building at the Yongbyon fuel fabrication plant.[148]

According to Hecker: 'These facilities appear to be designed primarily for civilian power, not to boost North Korea's military capability. That can be accomplished much more expeditiously by restarting the

143 Ibid.

144 Ibid.

145 Siegfried S. Hecker, 'A Return Trip to North Korea's Yongbyon Nuclear Complex', 20 November 2010, 6.

146 Ibid.

147 Ibid., 1.

148 Ibid., 4.

dormant 5MWe gas-graphite reactor, constructing a new gas-graphite reactor and conducting additional nuclear tests; but *we saw no evidence of continued plutonium production at Yongbyon*.' That said, Hecker admitted, 'the uranium enrichment facilities could be readily converted to produce highly-enriched uranium (HEU) bomb fuel (or parallel facilities could exist elsewhere) and the LWR could be run in a mode to produce plutonium potentially suitable for bombs, but much less suitable than that from their current reactor.'[149]

Overall assessment

Over the least three decades, efforts to influence and scale back the DPRK's nuclear programme have oscillated back and forth between engagement and confrontation, to varying effect. Moreover, within efforts to engage North Korea, there has been a tension between achieving long-term objectives (i.e. the disarmament of the DPRK) through the application of various interim steps (i.e. freeze or disablement).

Throughout all phases of engagement with the DPRK, the US and its allies have asserted that the ultimate goal has been the dismantlement of the North Korean nuclear weapons programme. Nevertheless, the policies taken to achieve that in the interim were different. Following the relatively easy restart of the programme in 2002, after North Korean nuclear activities were frozen for several years, the US insisted on extra measures that would add a level of irreversibility but which remain short of complete dismantlement.

The resulting policy of disablement aimed at making it more difficult for North Korea to restart nuclear operations. Such measures were not designed to stop the DPRK from regaining the operational status of their facilities, but instead to make that process more challenging and more time-consuming.

Consequently, any assessment of the measures taken during the freeze and during disablement should not be informed by the ability of North Korea to reverse them, but rather to what extent such measures made reversal difficult. Hecker's assessments have shown that the intended effect of disablement actions—that is, to slow down reversal—were successful, considerably more so than the earlier freeze. The fact that North Korea was able to reverse these steps after it abandoned the six-party process in 2009 stems only from the fact that steps were never intended to be irreversible measures.

The case of North Korea, and particularly the deterioration of the Yongbyon fuel fabrication facility, clearly illustrates the importance of facility maintenance on the prospects for ongoing and future operation. Which suggests that maintenance is a factor of critical importance, and especially so if a freeze or a process of disablement is to stretch over a long period of time. Moreover, the success of the technical measures taken to introduce a level of irreversibility in the DPRK's case ultimately depended on the political will to uphold them. This factor remains important for the ultimate success of any and all such measures.

Interim measures, as long as they remain short of dismantlement, will most likely involve leaving a disarming state with a hedging capability. The DPRK insisted that the full dismantlement of its reactor would only occur in sync with the supply of light-water reactor technology and other inducements. And efforts to convince the DPRK to accept disablement measures that would have more lasting consequences on its facilities failed. The DPRK was keen to maintain a hedging capability and this dynamic is likely to be influential in defining the agreed level of disablement in the future. Indeed, any disarming country is likely to resist giving up all control of its nuclear activity pending conclusion of a final settlement. A level of hedging, whether explicitly or implicitly defined, will likely be a necessary component of all temporary arrangements.

149 Ibid., 1 (Emphasis added) With regard to disabling centrifuge facilities, Albright and Brannan (2007, 16-17) note that: 'To the extent that facilities exist to make and operate centrifuges, they should first be turned off, all nuclear material removed, and placed under IAEA monitoring. The DPRK should agree not to conduct any maintenance of the facilities, except those necessary for ES&H reasons.

Annex III: Libyan nuclear disarmament

On 19 December 2003, after many years of diplomatic and economic isolation on the world stage, Libya made the surprise announcement that it would dismantle its weapons of mass destruction (WMD) programmes and open the country to immediate and comprehensive verification inspections. Libya undertook to eliminate all elements of its chemical and nuclear weapons programmes, declare all nuclear activities to the IAEA, eliminate ballistic missiles with ranges above 300km or payloads greater than 500kg, accept international inspections in line with commitments under the NPT, and sign up to the IAEA's Additional Protocol. Furthermore, Libya stated that it would eliminate not just its chemical weapons programme but its stocks of chemical weapons also, in a verifiable manner, and that it would join the Chemical Weapons Convention (CWC).[150]

In the case of Libya, which never developed nuclear weapons, a lack of knowledge of nuclear weaponisation was one of the principle hurdles that the country was unable to overcome—the reverse of the endurance of knowledge problem, in effect. What the Libyan case shows very clearly, however, is that in the pursuit of disarmament, and in attempting to make that disarmament as irreversible as possible, the cooperation and/or acquiescence of the state concerned can potentially 'make or break' disarmament efforts. A major factor in the problems encountered with regard to North Korea has been (and remains) the lack of sustained and willing cooperation from the North Korean side. Libya's willingness to cooperate with the IAEA and with other interested parties, and to submit to the physical removal of nuclear weapons-relevant items from its national territory imbued the case of Libyan 'disarmament' (after all, the country had no nuclear weapons to be disarmed of) with a measure of irreversibility that would not have been possible were the Libyan regime less inclined to play its part.

Background to the Libyan decision

As Sharon Squassoni and Andrew Feikert of the Congressional Research Service have noted, Libya's decision likely rested on a number of factors: 'The burden of 30 years of economic sanctions had significantly limited oil exports and stagnated the Libyan economy, helping to tilt the balance against pursuing WMD. Further, Libya's elimination of its WMD programs was a necessary condition for normalizing relations with the United States.'[151] Some in the administration of US President George W. Bush also suggested that US invasion of Iraq in Spring 2003, and the October 2003 interdiction of a Libyan-bound freighter carrying centrifuge parts, helped provoke the Libyan decision.[152]

Among supporters of the view that the Iraq invasion helped focus minds in Tripoli was the US Energy Secretary Spencer Adams, who stated that US military action against Saddam Hussein for his country's alleged possession of WMD 'did not escape the attention of the Libyan leadership.' The US undersecretary of defence, Douglas Feith, remarked that for the Libyan leader, Muammar Gaddafi, avoiding US opprobrium 'became even more urgent' when he saw the fate of the Taliban regime in Afghanistan and Saddam Hussein in Iraq. As Sammy Salama has noted, many drew a 'correlation between Libya's decision to capitulate to international demands and the 2003 invasion of Iraq by US-led coalition forces,' pointing to the timing of the Libyan announcement—very soon after the capture of Saddam—and reported remarks by the Libyan president that he was 'afraid' because of what had taken place in Iraq.[153]

150 Sharon A. Squassoni and Andrew Feickert, 'Disarming Libya: Weapons of Mass Destruction', Congressional Research Service, April 2004, 1–2.

151 Ibid., 2.

152 Arms Control Association Chronology of Libya's Disarmament and Relations with the United States: http://www.armscontrol.org/factsheets/LibyaChronology (accessed 4 December 2010).

153 Nuclear Threat Initiative Libya profile: http://www.nti.org/e_research/profiles/Libya/Nuclear/index.html (accessed 4 December 2010).

Others disagree though, Salama notes, and argue instead that the Libyan decision in fact had little to do with events in Iraq. 'According to this view, Libya's decision to disarm reflects the tail-end of many years of diplomacy between Libya and the West that was aimed at resolving various issues, including Libya's compensation for the families of the Pan Am 103 terrorist bombing over the Scottish town of Lockerbie in 1988, Libya's overall support for terrorism, the lifting of economic sanctions, and the surrender of Libya's WMD arsenal.'[154] Intriguingly, according to the CRS, at least two accounts record Libyan offers to renounce its WMD programmes as far back as 1992 and 1999, long before the invasion of Iraq.[155]

The 1999 case was brought to light by the former Clinton administration official Martin Indyk, who has revealed that Libya offered to give up its WMD arsenal then at the outset of secret negotiations with the US. At the time, Libya was experiencing major economic difficulties brought on by a combination of international sanctions—which severely constrained its ability to realise the full potential of its oil reserves—and flawed domestic economic policies. As Salama argues, the ex-Libyan leader Muammar Gaddafi 'is said to have realized at some point that in order to relive Libya's economic strife, he needed to mend fences with the United States,' who at that time were more interested in securing compensation for families of the victims of the Pan Am 103 terrorist attack and stopping Libyan support for terrorism. The country's WMD programmes were not seen as imminent threats, Indyk noted, and thus there was no urgency in accepting the Libyan offer to surrender them.[156]

Elsewhere it has been suggested that the Libyan WMD programmes were simply not very successful, while ending Libya's pariah status became a particularly important issue for Gaddafi.[157] Thus Libya would gain a lot, in terms of international standing, for not much of a loss in terms of WMD capability.

The extent of the Libyan nuclear programme

Libya became a party to the NPT in May 1975 and its NPT safeguards agreement with the IAEA entered into force in July 1980. Prior to 20 December 2003, Libya's declared nuclear programme consisted of a 10MW(th) IRT research reactor—in operation since 1980 and utilising 80 per cent enriched uranium—and a Critical Assembly (100W), both located at the Tajura Nuclear Research Centre (TNRC). Prior to December 2003, the total quantity of declared nuclear material under safeguards in Libya amounted to 20kg of uranium-235 in high-enriched uranium fuel form and 1,000 tonnes of uranium ore concentrate (UOC).[158]

On 20 December 2003, the day after the Libyan announcement, the IAEA director-general, then Mohammed ElBaradei, met with a Libyan delegation in Vienna where he was informed that for more than a decade Libya had been working on developing a uranium enrichment capability. According to the IAEA report of the meeting, this included 'importing natural uranium and centrifuge and conversion equipment, and the construction of a now dismantled pilot scale centrifuge facility.' Some of these activities should have been, but were not, reported to the Agency. The Libyans informed ElBaradei that the Libyan enrichment programme 'was at an early stage of development', that no industrial-scale facility had been built, and no enriched uranium produced.[159]

154 Ibid.

155 Sharon A. Squassoni and Andrew Feickert, *Disarming Libya: Weapons of Mass Destruction*, 2.

156 NTI Libya profile.

157 Sharon A. Squassoni and Andrew Feickert, *Disarming Libya: Weapons of Mass Destruction,* 2.

158 IAEA Board report: 'Implementation of the NPT Safeguards Agreement of the Socialist People's Libyan Arab Jamahiriya', GOV/2004/12, 20 February 2004, 1.

159 Ibid., 2.

Significantly, the Libyan delegation also told that Libya had obtained nuclear weapon design and fabrication documents. But expressed their commitment to ensuring that, henceforth, all nuclear activities in the country would be solely dedicated to peaceful purposes.[160]

In late December 2003, ElBaradei and a team of senior technical and legal experts from the Agency travelled to Libya, where they visited nine locations 'related to undeclared nuclear activities' and initiated a process of verifying Libya's previously undeclared nuclear materials, equipment, facilities and activities.[161] In late January 2004, another team of IAEA inspectors—including nuclear weapon and centrifuge technology experts, visited Libya to continue the verification process. Libya informed the Agency that, 'pursuant to mutual understandings' with the UK and USA, 'Libya had agreed to transfer to the USA sensitive design information, nuclear weapon related documents, and most of the previously undeclared enrichment equipment, subject to Agency verification requirements and procedures.'[162]

During ElBaradei's initial visit to Libya, the Agency was informed that the undeclared Libyan nuclear programme had involved over 12 sites since the beginning of the 1980s. According to the Agency, the programme was described by Libya as including nuclear material and facilities, as well as uranium conversion and enrichment facilities, which it had failed to declare to the IAEA as required by its NPT safeguards agreement. Libya also provided the Agency with 'information on nuclear cooperation with other countries as well as information on some of the sources of sensitive nuclear technology.'[163]

Imports of nuclear material

As the IAEA's report February 2004 report on Libya notes, the country declared that it imported a total of 2,263 tonnes of UOC between 1978 and 1981. One thousand tonnes had been imported in 1981 and declared to the Agency in accordance with the Libyan safeguards agreement. Libya declared that the remainder had been imported before its safeguards agreement came into force.[164]

According to the IAEA, in December 2003 'Libya provided information about the export in 1985 of some of the UOC for processing into a variety of uranium compounds.'[165] The recipient state (which an IAEA report of September 2008 identifies as the USSR) then reportedly transferred 56kg of natural uranium—divided up as 39kg of UF6, 5kg of UF4, 6kg of UO2 and 6kg of U3O8—back to Libya the same year. Those imports, which Libya was required to report to the IAEA under its safeguards agreement, went unreported. During their visit in January 2004, Agency inspectors verified these uranium quantities, placed the UF6 under seal and transferred it out of the country.[166]

Libya reportedly also told the Agency that in September 2000 it had imported 'two small cylinders' containing UF6, and in February 2001 'one large cylinder' of the same substance, which on both occasions it also failed to report to the IAEA. Using non-destructive assay techniques, the IAEA determined that the large cylinder contained some 1.7 tonnes of low-enriched uranium (approximately one per cent uranium-235) and that the two small cylinders held natural and depleted uranium. 'The contents of all three UF6 cylinders were verified by Agency inspectors, placed under Agency seal and transferred out of Libya,' the IAEA's report of February 2004 noted.[167]

160 Ibid., 2.2.

161 Ibid., 2.

162 Ibid., 2–3.

163 Ibid., 3.

164 Ibid.

165 Ibid.

166 Ibid., 3–4.

167 Ibid., 4.

Libya reportedly also indicated that, in 2002, it had imported uranium compounds from another country (described as 'through a clandestine source' by the IAEA in 2008),[168] mostly in solution form, for use as standards in chemical laboratories.[169] As the Agency noted in September 2008: 'The labelling of the containers indicated an effort to conceal the fact that the compounds were nuclear material.'[170]

Uranium conversion-related activities

According to the IAEA's February 2004 report, Libya stated that during the 1980s it had conducted undeclared laboratory-scale and bench-scale uranium conversion experiments at its TNRC site 'using imported UOC and possibly other imported uranium compounds.' All of which it failed to report to the Agency as required by its safeguards agreement. Libya also failed to provide the IAEA with design information for the facilities where these experiments took place.[171]

In August 2004, the Agency reported that from 1981 Libya was engaged in discussions with 'a foreign company' over the construction of 'a series of uranium conversion laboratories and facilities.' According to Libyan authorities, three projects were envisioned: first, a chemical, mineralogical and ore-processing laboratory consisting of three buildings (to be located in Sabha); second, a project involving the construction of laboratories for the conversion of yellowcake into UO_3 and conversion of UO_3 to UF_4 (this project reportedly also included the option of a uranium metal laboratory); and third, a project whereby uranium conversion laboratories would be constructed on a site adjacent to Libya's Renewable Energies and Water Desalination Centre (REWDC). None of these projects were implemented, however.[172]

According to the IAEA in 2008: 'Between 1983 and 1985, Libya actively pursued with a number of countries its efforts to acquire nuclear technology, with the longer aim of developing its own indigenous capability to produce fissile material.' These efforts reportedly resulted in the procurement of 'two boxes of documentation, in the form of microfiches, which contained information related to nuclear fuel cycle facilities.'[173]

In 1984, Libya reportedly ordered from abroad—from Japan according to the IAEA in 2008—a pilot scale uranium conversion facility, 'fabricated in portable modules in accordance with specifications provided by Libya,' which it partially assembled at Sawani in 1998. The modules were subsequently moved to Al Khalla and assembled into what would be called the Uranium Conversion Facility (UCF).[174] According to the IAEA, the first cold testing of the UCF was not conducted until February 2002. And in April that year, Libya decided to move the facility again, for security reasons. Reportedly, between March and October 2003, Libya dismantled, packed and moved much of the UCF to Salah Eddin, leaving only the milling and waste treatment modules at Sawani (although it is not clear from the IAEA report whether this was intentional or whether Libya intended to move these modules also).[175]

Importantly, Libya stated that no uranium was ever processed in the UCF. Moreover, according to Libya, the plant—which reportedly had an estimated annual feed capacity of 30 tonnes of uranium—could produce UF_4, UO_2 and uranium metal, but not UF_6. Libya apparently told the IAEA that it had tried to acquire

168 IAEA Board report: 'Implementation of the NPT Safeguards Agreement in the Socialist People's Libyan Arab Jamahiriya', GOV/2008/39, 12 September 2008, 4.

169 GOV/2004/12, 4.

170 GOV/2008/39, 4.

171 GOV/2004/12, 4.

172 IAEA Board report: 'Implementation of the NPT Safeguards Agreement in the Socialist People's Libyan Arab Jamahiriya', GOV/2004/59, 30 August 2004, 4–5.

173 GOV/2008/39, 4.

174 GOV/2004/12, 4.

175 Ibid.

UF6 production capability but without success, and that there had been no domestic production of UF6 in Libya, 'even on a laboratory scale.'[176]

Uranium enrichment

With regard to uranium enrichment (one of the so-called 'sensitive nuclear technologies' due to its weapons-relevance), Libyan authorities reportedly informed the IAEA that, in the early 1980s, a 'foreign expert' assisted by Libyan technicians 'initiated research and development on uranium gas centrifuge enrichment at Tajura, using a centrifuge design that the expert had brought with him.' Libya told the Agency that by the time this expert left, in around 1992, Libya was still not able to produce a working centrifuge and had not conducted any experiments using nuclear material. 'However,' the Agency noted, 'experience had been gained in the design and operation of centrifuge equipment, vacuum technology and mass spectrometry, which proved to be useful in the next phase of the enrichment programme.'[177]

That second phase, what might be called the 'procurement phase', of Libya's enrichment efforts began in January 1984, when Libyan officials met with Dr Abdul Qadeer (A.Q.) Khan of Pakistan. During this meeting, according to the IAEA's September 2008 report, 'Khan described to a senior Libyan official the technologies for acquiring nuclear material, and the necessary resources and capabilities,' as well as offering to sell Libya centrifuge equipment technology. But according to Libya, the Libyan official in question 'felt that the scientific and industrial requirements were too demanding for Libya in terms of resources and technological capabilities at that time, and a decision was made not to pursue the offer.'[178]

Between 1989 and 1991, further senior level meetings between Libyan officials and Dr Khan reportedly took place. 'These contacts led to a concrete agreement with [Dr Khan's black market procurement] network, and the acquisition, according to Libya, of information on L-1 centrifuge technology' as developed by Dr Khan. According to Libya, however, and as reported by the IAEA, the Libyan authorities felt that the value of the information provided by Dr Khan 'was not commensurate with what Libya had paid for it.' No complete centrifuges were provided to Libya as part of this particular deal.[179]

After coming clean about its past dealings, Libya told the Agency that back in July 1995 it had taken 'a strategic decision to reinvigorate its nuclear activities, including gas centrifuge uranium enrichment.'[180] According to the IAEA's September 2008 report on Libya, in 1995 the country re-established contact with the Khan network to acquire L-2 centrifuge technology. Two years later, Libya received 20 pre-assembled L-1 centrifuges and components for an additional 200.[181]

Libya later told the IAEA that the first successful test of a single L-1 centrifuge was completed by October 2000.[182] The test took place at Libya's Al Hashan site.[183] Starting in late 2000, Libya then started to progressively install 9-, 19- and 64-machine L-1 centrifuges at Al Hashan. By April 2002, the 9-machine cascade was installed and under vacuum, with all piping, electrical connections and process equipment installed. The 19-machine cascade was reportedly at a similar stage of completion, with the first 10 rotors installed but not under vacuum. The 64-machine cascade, together with its process equipment, was placed in

176 Ibid.

177 Ibid., 5.

178 GOV/2008/39, 5.

179 Ibid.

180 Ibid.

181 Ibid.

182 Ibid.

183 GOV/2004/12, 5.

position ready for installation. For security reasons, Libya decided at this time to dismantle all three cascades and move them to its site at Al Fallah, where it remained in storage, other than those parts transferred out of Libya following its 19 December 2003 renunciation of WMD. (Prior to the move to Al Fallah, no nuclear material was used on any centrifuge tests, according to Libya's later declarations to the Agency.)[184]

According to the IAEA's February 2004 report, Libyan authorities also stated that in September 2000, the same month it received its 'two small cylinders' of UF6, Libya received two L-2 centrifuges. Following receipt of these L-2s, Libya placed an order for a further 5,000 machines, an order it later increased to 10,000.[185] As the IAEA noted in September 2008, this order included 'all the required supporting equipment, including feed stations, product and tails withdrawal stations, vacuum equipment, cascade piping, drive systems and other miscellaneous equipment.'[186] According to the IAEA, the Khan procurement network acted as an intermediary for the manufacturing and shipping of the L-2 components and equipment from entities in a wide range of countries, including Japan, Malaysia, Pakistan, South Africa, South Korea, Turkey, the UAE, not to mention several in Europe.[187]

The components for the L-2s began to arrive in Libya in large quantities in December 2002. According to the IAEA, out of 10,000 centrifuges ordered, a 'considerable number' of parts, mainly casings had arrived by the time the Agency conducted inspection activities in late December 2003. 'However, according to Libya, no additional rotors were included in the shipments.'[188]

In late 2001, Libya also acquired a precision machine workshop—also through the network of Dr Khan.[189] The workshop, the Agency notes, was intended to support the gas centrifuge programme.[190] In February 2004, however, the IAEA stated that the equipment for the machine shop was still being stored in metal crates.[191] In February 2004 the IAEA also revealed a Libyan acknowledgement that 'it had also acquired a large stock of maraging steel and high strength aluminium alloy', which are 'essential for the production of centrifuge components.' This technology transfer reportedly included the training of Libyan personnel 'at foreign locations, on at least three occasions.'[192]

In August 2004, the IAEA reported that all L-1 and L-2 centrifuge parts and enrichment process equipment had been removed from Libya and taken to the USA that January, 'in accordance with an agreement between those two countries.'[193]

184 Ibid.

185 Ibid.

186 GOV/2008/39, 5.

187 GOV/2008/39, 5–6.

188 GOV/2004/12, 5.

189 GOV/2008/39, 6.

190 Ibid.

191 GOV/2004/12, 6.

192 Ibid. 6.

193 GOV/2004/59, 5. (According to an April 2004 report by the Congressional Research Service (p4-5), on 26 January 2004 US officials airlifted around 55,000lbs of documents and components from Libya's nuclear and ballistic missile programmes to the United States. Nuclear components reportedly included several containers of uranium hexafluoride gas, two P-2 centrifuges from Pakistan's Khan Research Laboratories and additional centrifuge parts, equipment and documentation. Then, in March 2004, in a statement by CRS that conflicts with the IAEA's assertion that all centrifuge parts were removed in January 2004, over 1,000 tons of additional centrifuge parts and MTCR-class missile parts were reportedly shipped out of Libya, including five Scud-C missiles, partial missiles, missile launchers and related equipment. The CRS note also that Russia removed 13kg of 80 per cent HEU fuel that it had supplied for Libya's IRT research reactor in the 1980s. The Wikileaks cables exposure of 2011 show that in November 2009 President Gaddafi blocked the repatriation of 5.2kg of HEU to Russia, apparently in protest at the state of Libyan-US relations. See: http://www.guardian.co.uk/world/2010/dec/03/wikileaks-cables-libya-enriched-uranium (accessed 10 December 2010)).

Irradiation, reprocessing and other fuel cycle-related activities

In February 2004, the IAEA stated that Libya had until recently failed to report 'the fabrication of several dozen small uranium oxide and uranium metal targets, on a gram scale, and their subsequent irradiation in the Tajura Research Reactor between 1984 and 1990, to produce mainly fission product radioisotopes.' According to the Agency: 'Thirty-eight of the targets, each containing about one gram of uranium, were dissolved and radioisotopes extracted using ion exchange methods or solvent extraction at the hot cells at the adjacent radiochemical laboratory. Forty-eight additional targets were irradiated but not processed, and are currently stored in one of those hot cells.' Libya also reportedly indicated that very small quantities of plutonium were separated from at least two of the irradiated targets.[194]

In September 2008, the IAEA reported that from the mid-1980s, 'Libya pursued efforts to acquire fuel fabrication and reprocessing technology' through an intermediary 'who had also provided assistance in connection with Libya's chemical weapons programme.' The 'most advanced negotiations' were reportedly held in over plans for a pilot reprocessing facility, 'which proceeded in the late 1980s to the stage of a detailed design.' According to the IAEA, the fuel fabrication laboratory and the reprocessing plant were both based on technology of German origin, but Libya told them that 'neither equipment nor a complete set of drawings had been delivered by the time the projects were stopped at the end of the 1980s.'[195]

Nuclear weaponisation-related activities in Libya

As the IAEA put it in February 2004: 'Libya has acknowledged that it had received documentation related to nuclear weapon design and fabrication from a foreign source.' These documents, copies of which were passed to the USA and UK by Libya prior to the IAEA's visit to Libya in December 2003, were reviewed by Agency experts in January 2004 and subsequently transferred to the USA. The documents reportedly included 'a series of engineering drawings' relating to nuclear weapon components and notes (many of them handwritten) related to the fabrication of weapon components. 'The notes indicate the involvement of parties other than Libya,' the Agency's report said, 'which will require follow-up investigation.'[196]

According to Libyan officials, as reported by the Agency, Libya received the documents around the late 2001/early 2002 mark. Libya stated, though, that it 'did not take any steps to assess the credibility or explore the practical utility of the information available in the documents.' Moreover, the Agency recorded, Libya stated that it had 'no national personnel competent to evaluate the data' and that it would have 'asked the supplier for help in the event it had opted to take further steps to develop a nuclear weapon.'[197]

For verification purposes, the IAEA called on Libya 'to disclose all capabilities [then] existing in Libya that could contribute to weaponisation activities.' Following that request, Libya subsequently provided the Agency with information that led to the inspections of 18 sites around the country—all locations identified by Libya as sites 'that could have, from a technical standpoint, provided support to a nuclear weapon research and development programme.' The locations included those related to the handling of high explosives, ammunition production, missile propellant fabrication and testing, missile warhead design and manufacture, metal casing, welding and machining, as well as sites involved in the research, development and production of chemical and plastic materials.[198]

194 GOV/2004/12, 6.

195 GOV/2008/39, 6.

196 GOV/2004/12, 6.

197 Ibid.

198 GOV/2004/12, 6–7.

As the Agency's February 2004 report noted, while it had identified some infrastructure and dual-use equipment that 'could represent capabilities useful for a weapon development programme, initial inspections of these locations did not identify specific facilities . . . dedicated to nuclear weapon component manufacturing.'[199]

Overall assessment

As verification activities subsequently confirmed, from at least the mid-1980s until 2003 the Libyan nuclear programme was geared principally toward the development of nuclear weapons. But Libya got nowhere near as far as North Korea or South Africa. Libya was able to obtain information on the design of a nuclear weapon, but its lack of sufficiently knowledgeable personnel meant that it could make little of the documentation in its possession. Indeed, as the IAEA noted in 2008, during the course of its investigations into Libya, it 'did not find any indications of actual work related to nuclear weapons development.'[200]

As noted earlier, Libya's openness and willingness to facilitate the verification process undertaken by the IAEA—regardless of the motives for cooperation—made that process far simpler than would have been the case otherwise. Allowing all nuclear weapons-relevant equipment (especially its centrifuge technology) and documentation to be taken out of the country signalled a strong commitment to the principle of irreversibility, even if, in this case, that irreversibility did not relate strictly to disarmament since Libya had no nuclear weapons to be disarmed of.

199 Ibid. 7.

200 GOV/2008/39, 7.

Annex IV: Verifying nuclear warhead dismantlement in South Africa

South Africa has the distinction of being the only country to develop weaponised nuclear explosives and then publicly give them up. This makes South Africa a particularly appropriate example of how a country can approach denuclearisation. The case of every country will be different and South Africa's political and social reasons for giving up nuclear weapons will probably not be repeated, but the processes of giving up weapons in an irreversible way are highly instructive.

South Africa's nuclear program began in the 1960s when the government wanted to sell large quantities of uranium abroad. It felt that adding value to the uranium by enriching it before sale was a good economic decision for the state. Because South Africa was already considered a pariah for its racial policies, it was difficult to obtain enrichment technology and it set about developing its own aerodynamic uranium isotope separation system. This system was unique and developed largely in secret. In the process of this development it appears that forces within the government changed the direction of this enrichment program from a peaceful to a clandestine military program. There are some reports that the development of nuclear explosives was also tied to the development of so-called Peaceful Nuclear Explosives (PNE). PNE were viewed positively in the United States and Soviet Union in the 1960s and were considered for a range of applications ranging from digging canals to stimulating natural gas fields and fracturing rock for mining. South Africa, a major mining state was in step with other countries in considering that PNE might be beneficial to its mining industry.

South Africa was isolated and faced external threats in the 1970s and 1980s. The country's apartheid racial policy caused it to be isolated from most developed states. Embargoes and sanctions on military activities hampered free trade. Neighbouring black states viewed the white regime in Pretoria as a threat to regional stability. Rebels in both Mozambique and Angola were involved in armed clashes with South Africa. In Angola, Cuban troops were supporting Angolan forces. The Cubans, with contemporary Soviet defensive and offensive systems had South Africa bottled up in its own territory, unable to project its force into Angola. A nuclear deterrent seemed one way of balancing the military force.

It must be noted that nuclear weapons were developed by a powerful bloc in the civil nuclear programme of the South African government. The military high command was not enthusiastic about nuclear weapons because they were not particularly useful for fighting against dispersed troops on a desert battlefield. After ten years of development, only seven nuclear devices had been produced and the programme was capped at that number. The civil nuclear program attempted to keep a program alive by considering more advanced types of nuclear weapons but it was clear that enthusiasm within the government had waned and the weapons were seen as more a hindrance than a help.

The military programme was an open secret. Intelligence agencies knew about the huge enrichment plant at Pelindaba. The Russians discovered an underground nuclear test site in 1977 and South Africa was warned by the US not to carry out any nuclear test. Consequently, when South Africa suddenly decided to allow the IAEA to begin inspecting hundreds of kilograms of weapons-grade uranium metal ingots, it was clear that something was changing. In fact, the government of South Africa saw that a huge change in the country's politics was imminent and decided to dismantle its weapons rather than turn them over to the incoming government. This culminated in South Africa signing the Nuclear Nonproliferation Treaty (NPT) in 1991. In March 1993 President de Klerk gave a speech to parliament declaring that the former weapons programme was finished. He gave many details of the programme, including that the programme had been dismantled before the country signed the NPT, that the nuclear material was under IAEA safeguards and that most documentation had been destroyed. This was the situation confronting the IAEA in 1993.

The IAEA's role

The IAEA was charged with discovering the extent of South Africa's announced programme and verifying its complete dismantlement. This was made difficult by the fact that much of the associated documentation had been destroyed and the nuclear material had been converted into metal ingots from the previous weapons configuration. This gave investigators little hard evidence to verify. South Africa also imposed some conditions on the process.

The process of verification of the destruction of the weapons was to be conducted during 'visits' and not during 'inspections.' This dealt with the fact that South Africa's nuclear weapons programme was dismantled before it signed the NPT and was therefore not subject to 'inspection.'

Investigators (not inspectors) could not ask about the source of foreign supply of material or concepts. This was because there were still sanctions on the country and certain individuals who had been involved in questionable imports were on watch lists or under threat of prosecution in the West. South Africa did not want to give information that could be used as evidence against these individuals.

The IAEA was also not allowed to ask any questions about delivery systems for the nuclear weapons. This was a military secret that it wanted to protect. (This did hamper the investigation at times.)

The IAEA was used to handling confidential information. It is a normal practice that nuclear materials investigations and information from a state is always protected. In addition, most information about the nuclear fuel cycle is unclassified or classified at a low level so that safeguards inspectors normally have access to it. But there was a different issue with respect to nuclear weapons design. Very few people in the IAEA have experience with nuclear weapons design, and they are prohibited from discussing it by their national security agreements. Hence, the IAEA had to come up with a plan for how to assess weapons information without actually disclosing it to the majority of IAEA employees and not compromising those among their own staff that might have relevant experience.

During inspections of Iraq's secret nuclear weapons program in 1991, the IAEA used many inspectors seconded by member states with weapons programs. In the case of South Africa, the IAEA did not want to involve non-IAEA employees. The solution was to use one appropriately-cleared employee and have their findings vetted by a second weapons state. Only a summary of the findings was given to IAEA management without any details that would contribute to nuclear weapon design proliferation. Even so, many team members were exposed to many bits of weapons design information that could not be controlled.

Irreversibility in South Africa

Irreversibility of the physical programme occurred in several ways. First, the country made a political commitment to not resuming weapons development and began to destroy all documentation and nuclear weapons designs. Engineering drawings and papers were destroyed except for information needed to safely disassemble the weapons, and to convert the material into non-weapon shapes. An independent auditor from a South African university was appointed to oversee the dismantlement and destruction. He approached his task from an academic orientation and mostly audited events at random. He counted upon the engineers tasked with dismantlement to carry out their jobs conscientiously. There was no international verification of this process because it took place before the programme was publicly disclosed internationally.

The enriched uranium components were melted down into criticality-safe ingots and eventually placed under IAEA nuclear material safeguards. (South Africa did not have to declare the origin of the material at the time it was turned over to the IAEA.) The ingots were placed in highly secure storage at Pelindaba and were slowly used up as targets for medical isotope production in the research reactor located there.

Many non-nuclear components were left over as a result of the dismantlement process. These included internal components of the weapons that were made of ordinary materials, not nuclear material. Many of these components were still available when the IAEA visits began in 1993.

The special machine shop near Pelindaba contained several pieces of equipment that were directly suited to support the weaponisation process. These items, such as some isostatic presses, were transferred to other industries and were inspected by the IAEA from time-to-time to see that they had not been returned to prohibited purposes. Other more ordinary machine tools were sold off, and some were verified for a time before they were considered to be of no threat in a country that had clearly de-nuclearized.

All enrichment using South Africa's unique Helikon, aerodynamic enrichment process was terminated. The facilities for enrichment were dismantled and destroyed. The process equipment contained large amounts of uranium, including highly enriched uranium that had plated out in the pipes and separators over the years. Accounting for all of this material has been a laborious process that continues even to this day.

South Africa had two other small enrichment research efforts that were eventually dismantled also. The country had put significant resources into Molecular Laser Isotope Separation (MLIS). The research efforts were reasonably successful. This was unusual because most industrialized states pursuing Laser Isotope Separation were using the Atomic Vapor process (AVLIS) and were having limited success. The new government lead by the African National Congress (ANC) studied the process and decided it was uneconomic. It was terminated in 1997. There are reports that South Africa contracted with Iran for assistance with lasers in the context of LIS.

South Africa also had a small gas centrifuge programme to enrich uranium isotopes. This program was very small scale and did not use a large quantity of uranium. It did, however, develop advanced centrifuge technology including documents and theory that would be of considerable use to another state intending to develop gas centrifuges. The centrifuge programme was abruptly stopped before South Africa disclosed its nuclear weapons programme. As a result, the documentation of the dismantlement and the disposition of documentation and equipment are poor to non-existent.

South Africa had also dug two deep nuclear test shafts in the Kalahari Desert. These test shafts were discovered by a Soviet reconnaissance satellite in 1977. The Soviets passed the information on to the United States for investigation. The Soviets at the time were supporting Cuban troops in Angola who in turn were attacking South Africa. The United States was considered more of an 'ally' of South Africa—despite international sanctions. The US demarched South Africa over the suspected nuclear test shafts and South Africa immediately shut down all activity at the Kalahari Desert site. In 1988 there was some refurbishment activity noted at the site. This became a high priority for IAEA investigations of the former nuclear weapons programme.

South Africa took teams to the site and showed them that the test shafts were still usable for a nuclear test. The two parties agreed to backfill the test shafts with sand, metal debris and concrete to prevent them from ever being used for testing purposes—significant from the point of view of irreversibility.

Overall assessment

South Africa was able to irreversibly dismantle its nuclear weapons program for a number of reasons:

- External threats from Mozambique and Angola subsided.
- Military leaders were glad to give up a weapon they never really wanted.
- Interest in PNEs disappeared.

- Radical changes from a racially-divided society to a modern democracy completely changed the form of government and culture of secrecy.
- Accession to the NPT was necessary to dissolve sanctions against the country and complete adherence to the NPT was important to the country's leaders.

Physical verification of the denuclearisation was complicated because the work was done in secret, with inadequate documentation of the processes. Successful verification depended on several factors:

- South African authorities showed a remarkably high degree of openness and cooperation.
- Records of highly enriched uranium production were consistent with declarations of weapons produced.
- Weapons grade uranium metal ingots were available for safeguards.
- The IAEA had an experienced nuclear-weapon expert on the staff at the time, but this is not always the case.
- Non-nuclear components that remained after dismantlement were consistent with declarations.
- Some weapons design/production information remained and could be evaluated and then was destroyed.
- Government policy and budgeting documents were not destroyed and could be used to verify program development declarations.

Verification in South Africa was hampered by a lack of documentation but this was overcome by piecing together other information. Nuclear materials seem to have been completely removed from weapons and placed under IAEA safeguards. The only element of concern that remained was the knowledge that remained with former weapons program staff. These people lost their careers and needed to find alternate employment. A few helped the A.Q. Khan network develop its centrifuges, hence the concern about lack of proper documentation of the dismantlement of the centrifuge program. But there is no sign that any weapons design information was lost in the process.

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