VERIFICATIONMATTERS

VERTIC RESEARCH REPORTS ● NUMBER 5 ● JULY 2006

IAEA verification of military research and development

James Acton with Carter Newman

VERTIC

James Acton is a VERTIC Polden-Puckham Science Fellow. He holds a Ph.D. in theoretical physics from the Cavendish Laboratory at Cambridge University and a B.A. (Hons.) and M.Sci. in Natural Sciences from Trinity College, Cambridge University. He has worked as a research associate at the Cavendish Laboratory.

Carter Newman holds a B.A. (Hons.) in Philosophy, Politics and Economics from the University of Hull, and gained her M.A. in War Studies at the Department of War Studies, King's College London in 2005. She was a VERTIC intern during the spring of 2006.

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Current funders
Esmée Fairbairn Foundation; Ford Foundation; Global Opportunities Fund (GOF) administered by the UK Foreign and Commonwealth Office (FCO); John D. and Catherine T. MacArthur Foundation; Ploughshares Foundation, Polden-Puckham Charitable Foundation; Joseph Rowntree Charitable Trust

Series editor: Michael Crowley
Contributing editor/project manager: Andreas Persbo
Sub-editor: Eve Johansson
Design and production: Richard Jones

Acknowledgements
VERTIC wishes to thank John Carlson, Mark Fitzpatrick, Glenn Kelly, Ian Kenyon, John Simpson and Peter Zimmerman for their invaluable comments on earlier drafts of this report. We also wish to thank those numerous others that prefer not to be named.

We are also grateful to several of our interns, who provided invaluable research support.

The Verification Research, Training and Information Centre (VERTIC), Development House, 56–64 Leonard Street, London EC2A 4JX, United Kingdom
Phone +44 (0)20 7065 0880 *Fax* +44 (0)20 7065 0890
E-mail info@vertic.org *Website* www.vertic.org

Printed in the United Kingdom by Linkway CCP Communications Limited

ISSN 1474-8045

Contents

Tables and figures

Acronyms and abbreviations

HEU	High enriched uranium
IAEA	International Atomic Energy Agency (The Agency)
INIS	International Nuclear Information System
NPT	Nuclear Non-Proliferation Treaty (1968)
NTM	National technical means
NWS	Nuclear weapon states
R&D	Research and development

Foreword

The International Atomic Energy Agency has been guardian of the nuclear non-proliferation regime since the 1950s. The organization's mission statement reads that it 'verifies through its inspection system that States comply with their commitments, under the Non-Proliferation Treaty and other non-proliferation agreements, to use nuclear material and facilities only for peaceful purposes'. Its central role in nuclear verification is uncontested and essential in the worthwhile effort to build trust among nations, and ultimately to realize the core objective of the organization's own motto, to promote 'atoms for peace'. To date, there have been few readily accessible studies on the Agency's role in detecting the research, assembly and testing of a nuclear weapon or a nuclear explosive device once a state has acquired the necessary quantity of nuclear material.

This study, which aims to explore some of these issues, has been conceptualized by VERTIC's arms control and disarmament programme for over a year. In early 2006, VERTIC was fortunate to be able to bring together a gifted and hard-working team to work on this report. The product, of course, does not rest solely on VERTIC's experience and deductive abilities. The material has been evaluated by a seminar of our peers. We are grateful to those reviewers, who were drawn from various strands of government in several European countries, from well-known research institutes and from highly respected universities. We are also grateful to those safeguards authorities and nuclear laboratories which have shared their many years of experience of the Agency's safeguards system with us. For me personally, project management has never been easier. It has been a pleasure to oversee this process.

Finally, and most importantly, we wish to thank the Polden-Puckham Charitable Foundation for funding this study, and for its continuing support for VERTIC's efforts to introduce gifted natural scientists to the exciting field of multilateral verification.

Andreas Persbo

Contributing editor/Project manager

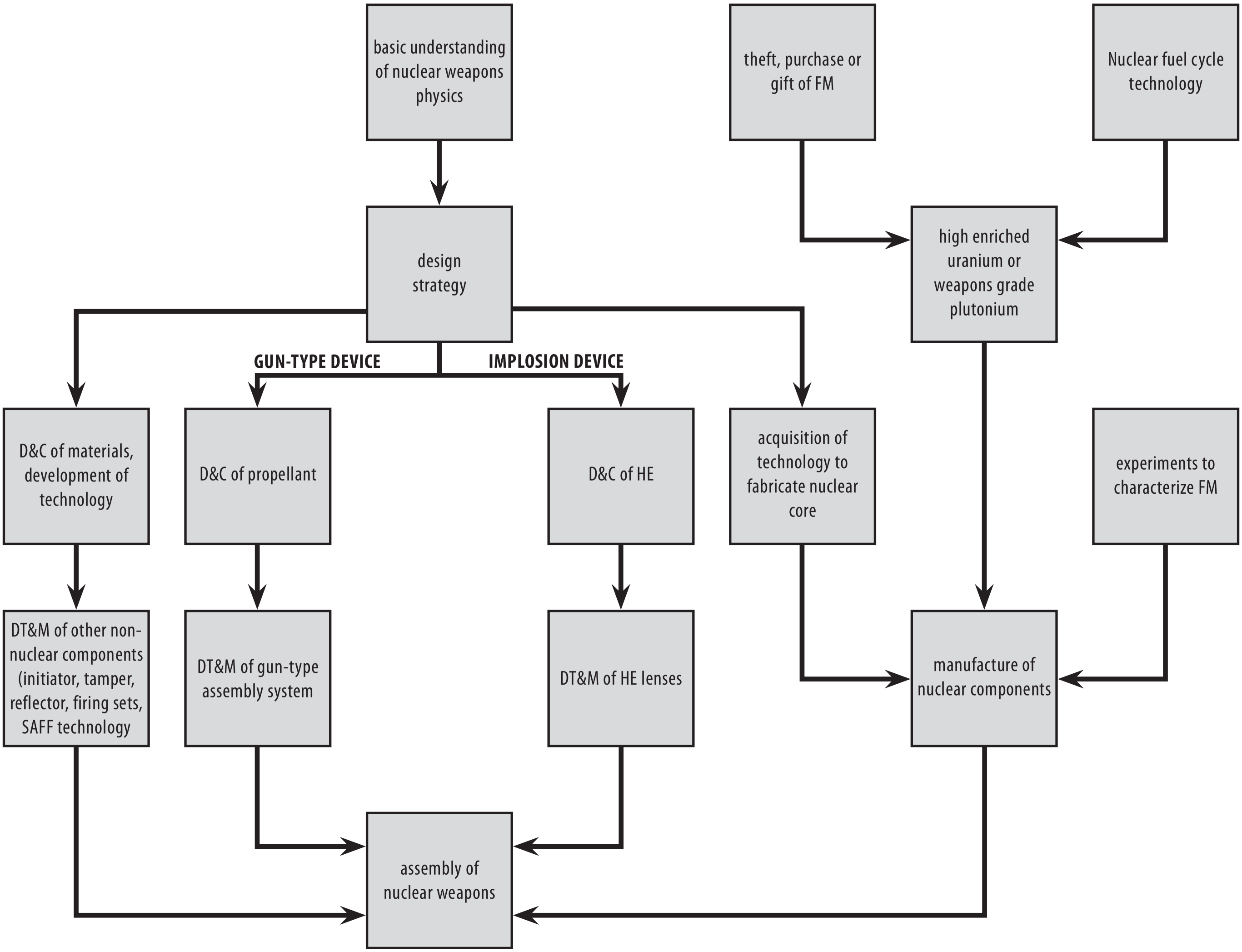
Introduction

The current verification regime is based upon the premise that if a state does not have access to fissile materials then it cannot manufacture a nuclear weapon. It therefore focuses on the monitoring and control of these materials. If no materials diversion or clandestine production is detected then a state is considered to be in compliance with its safeguards agreement. However, a state intent on developing a nuclear weapon must do more than acquire sufficient fissile material. To design and then manufacture a usable device, it must undertake an extensive research and development (R&D) programme—a process known as weaponization,[1] as summarized in figure 1. To some extent, the monitoring of weaponization activities falls outside the current safeguards regime. Despite a number of changes in International Atomic Energy Agency (IAEA) safeguards over the past decade, the system is still largely based around the concepts of accountancy and control of declared nuclear materials and facilities.[2] Traditionally, much less emphasis has been placed on the verification of small-scale military R&D activities, which can be very difficult to detect and assess.

In recent years, with the adoption of additional protocols by an increasing number of states, the ability of the Agency to detect clandestine fuel cycle activities has been significantly enhanced.[3] Although there is scope to strengthen safeguards on fissile material still further, it may be useful to consider whether a regime designed to monitor military R&D is feasible or indeed desirable.

Before considering any changes to the IAEA's mandate, however, it is important to consider what the Agency is already entitled to do in this regard. This paper therefore begins by reviewing the Agency's existing authority to search for weaponization activities, as well as the experience it has gained of doing so. A general strategy for detecting the existence of an illicit nuclear weapons programme is then discussed. It should be stressed that this paper is not intended to be detailed or comprehensive. The strategy for detecting weaponization is, likewise, intended to be a general overview rather than a detailed plan of action. The reader should bear in mind that the paper aims to stimulate debate by presenting an assessment of the feasibility of uncovering

Figure 1 Schematic diagram illustrating the process of weaponization for a simple fission weapon



Note: In practice, weaponization is likely to be more complicated as design decisions are rethought in the light of experience. More steps would be necessary to manufacture a more sophisticated weapon, for example, one that can be delivered in a missile. **Key:** D&C = development and characterization; DT&M = development, testing and manufacture; SAFF = safing, arming, fusing and firing; HE = high explosives; FM = fissile material.

clandestine weaponization activities. All the technical material presented in this paper is based solely on information already in the public domain; the authors have no access to classified information about weaponization. In order to facilitate a transparent and effective peer-review process, the discussion of the current non-proliferation regime is also based solely on open source literature. This has had the consequence that it has not been possible to discuss some of the finer details of the Agency's safeguards system (information-driven safeguards in particular).

It might be helpful to illustrate the process of weaponization with the Iraqi experience.[4] It can be convincingly argued that the biggest hindrance to Iraq's nuclear ambitions was its shortage of fissile material as a result of its failure to develop reliable enrichment technology. Weaponization, however, also proved a significant challenge. Constrained both by the amount of fissile material it had available and by the capacity of its delivery system, Iraq opted to develop an implosion device rather than a gun-type device. Although the former is more compact and uses less fissile material, it is also more complex to design and manufacture. A determined weaponization effort was begun in 1988. Three years later, at the time of the first Gulf War in January 1991, Iraq's programme was still incomplete. In particular, it had failed to perfect either an initiator[5] or explosive lenses.[6] Iraq would have required somewhere between a few months and a year longer to manufacture a primitive nuclear device.[7] Having achieved that milestone, the construction of a weapon suitable for delivery in a ballistic missile would have required a further year's work.[8] Even once the delays caused by a lack of fissile material have been taken into account, Iraq's weaponization programme, which was well-funded and led by scientists with many years of relevant experience, would have taken several years to complete.

A similar timescale is likely to apply for all but the most technologically advanced proliferators. Since it is important to be able to detect and assess non-compliant behaviour accurately and in a timely fashion, this paper examines whether, in practice, it is possible to uncover a clandestine weaponization programme within a window of opportunity similar to the timescale offered by the Iraqi programme. Early detection within this window would enable the international community to act, thus denying the violator the benefit of the breach.

In examining whether it is possible to detect non-compliant behaviour in a timely fashion, it is important to note that there are ways to short-cut the enrichment process. Fissile material can be obtained by theft or purchase. The acquisition path can also be speeded up, for example, by the employment of an acquisition strategy, such as the one used by Iraq, in which safeguarded high enriched uranium (HEU) from a research reactor is used as enrichment feedstock.[9] Thus if a state develops an effective material acquisition strategy then the availability of fissile material may no longer be the limiting factor. In this case weaponization may be the most significant barrier to the manufacture of a nuclear weapon. This scenario accentuates the need to develop a monitoring and verification system that is able to detect weaponization activities at an early stage.

What authority does the Agency currently have to verify military research and development?

Defining the question

In analysing the IAEA's authority to verify military research and development, there are three separate questions that must be addressed.

- First—and this is the most fundamental question—to what extent is weaponization prohibited by the 1968 Nuclear Non-Proliferation Treaty (NPT)?[10]
- Second, if the Agency has reason to suspect that a state is carrying out clandestine weaponization activities, can it instigate inspections to verify the suspect research? This question is very closely related to the issue of whether the Agency has the authority to verify all obligations assumed by states under the NPT or whether its powers are, in fact, more limited.
- Third, what powers does the Agency have to collect information which could be used to instigate inspections and reinforce their findings?

The distinction between the second and third questions is not merely of academic interest. Its importance can be illustrated in terms of the 'conventional' safeguards that are currently placed on nuclear material. The NPT obliges each non-nuclear weapon state to place safeguards on 'all source or special fissionable material in all peaceful nuclear activities within the territory of such State, under its jurisdiction, or carried out under its control anywhere'.[11] The NPT, however, does not include detailed provisions as to how this obligation is to be verified. Those are contained in the state's Comprehensive Safeguards Agreement with the IAEA (modelled on the text contained in INFCIRC/153).[12] This agreement gives the Agency the legal authority to draw conclusions about both the completeness and the correctness of states' declarations about their fuel cycle activities, but it does not give it sufficient authority to undertake all the verification activities necessary to be able to draw credible conclusions about the absence of undeclared materials or activities within a state.[13] Following the discovery of Iraq's nuclear programme, the Agency launched its Programme 93+2 to develop a remedy for this problem. Its result was that in addition to using its existing powers more fully, the Agency drafted the Model Additional Protocol, which aims to give the Agency the means to be able to provide credible reassurance about the absence of undeclared nuclear activities in a state.[14]

Were the Agency to be tasked with the verification of military R&D it would face a similar problem. Before it could request an inspection of a suspect industrial facility, it would need evidence that weaponization activities were being carried out there, either through information provided by states or through information collected through its own means. Here lies the crucial difference between looking for clandestine fuel cycle activities and looking for clandestine weaponization activities. A state which has clandestine fuel cycle facilities may have some declared facilities as well. In some circumstances, it should be possible to detect the former by analysing the consistency of a state's declaration about the latter. In contrast, weaponization activities would, for obvious reasons, never be declared by a state. A state's declaration cannot therefore be used as a 'starting point' for detecting clandestine weaponization activities in the same way that it can for clandestine fuel cycle activities.

To compensate for this, one of the Agency's other tools for detecting clandestine fuel cycle activities, sometimes referred to as 'information-driven safeguards' (the collection and analysis of information about states' industrial and scientific activities), would have to play a central part in any strategy for detecting clandestine weaponization activities. It is important, therefore, to examine not only whether the Agency is entitled to inspect suspect sites but also whether it has the power to gather the evidence that could be used to justify inspections.

Sources of authority

The Agency is the competent authority for verifying states' compliance with their safeguards agreements 'with a view to preventing diversion of nuclear energy from peaceful uses to nuclear weapons or other nuclear explosive devices'.[15] The IAEA's role is central and its mission enjoys broad support from NPT states parties. Indeed, at the 2000 Review Conference it was agreed that 'nothing should be done to undermine the authority of the Agency in this regard'.[16] For this reason, the discussion here is restricted to considering whether the Agency, as opposed to any other organization, has, or should have, the authority to verify military research and development.

To answer the questions identified above it is necessary to turn to the Agency's mandate. This is derived from a number of sources. At its heart lies the 1956 Statute of the International Atomic Energy Agency.[17] For most states, the Agency's authority also derives from the NPT and the corresponding safeguards agreements concluded between the Agency and individual states parties to the NPT. There are two principal safeguards documents to take into account, namely the widely adopted Model Comprehensive Safeguards Agreement (INFCIRC/153) and its Additional Protocol (INFCIRC/540).[18] The latter contains several measures which strengthen the safeguards regime.

Does the NPT prohibit weaponization? The meaning of the word 'manufacture'

Article II of the NPT prohibits non-nuclear weapon states from manufacturing nuclear weapons. The term 'manufacture' is not defined in the treaty, and this has been highlighted by several observers as a major definitional weakness, if not a loophole, in the NPT. Consequently, there is a lack of clarity about whether weaponization activities prior to the actual assembly of a nuclear weapon are prohibited.

The topic was discussed during negotiations on the treaty and—as is often the case in sensitive multilateral negotiations—agreement was sought in 'purpose criteria'. The unchallenged view[19] is that:

> *Facts indicating that the purpose of a particular activity was the acquisition of a nuclear explosive device would tend to show non-compliance. (Thus the construction of an experimental or prototype nuclear explosive device would be covered by the term 'manufacture' as would be the production of components which could only have relevance to a nuclear explosive device.)*[20]

These criteria are surprisingly narrow. Apart from stating that the assembly of a prototype nuclear device is prohibited, the only other example given to illustrate the meaning of the term 'manufacture' is 'the production of components which could only have relevance to a nuclear explosive device'. On balance, however, this would seem to support the view that the manufacture of a nuclear weapon occurs at some time before its final construction.

The purpose criteria hold that an activity is illegal if it is carried out with the intention of furthering a nuclear weapons programme. In the light of this, it is natural to ask why the Agency looks for the diversion of nuclear material rather than trying to assess intent. There are a number of reasons. First, the Agency derives its mandate from Article III of the NPT. This article envisages a very specific type of safeguards, namely controls placed on fissile material. Second, establishing a state's intent is notoriously difficult, as exemplified by the current debate on Iran's nuclear programme. Such difficulties promote the trend towards establishing a verification regime based on objective criteria. Finally, activities aimed at determining the intent of a state's leadership are similar to those normally conducted by national intelligence agencies, and it is clearly not in the interests of an international verification body, such as the IAEA, to be perceived as an extension of national intelligence agencies.

Is the IAEA entitled to inspect suspect facilities?

Voluntary and special inspections

Should the Agency suspect the existence of illicit weaponization activities in a state, it has two options: either it can ask the state for voluntary access or it can invoke its right of special inspections.[21] There is no specific authority in its mandate for requesting voluntary access. However, in the past, when the Agency has found an anomaly in a state's declaration, it has tended to ask for voluntary access rather than special inspections—presumably because the former are less confrontational. Since voluntary access also affords a suspect state the opportunity to prove its compliance then it also has value for states. In addition, requests for voluntary access are a useful tool for increasing the pressure on a state that is suspected of pursuing an illicit weapons programme.[22] The inspections resulting from voluntary access are, however, likely to be of limited use in the search for weaponization activities. The main reason for this is that a state is unlikely to give the Agency access to any weaponization activities. As noted above, it is clearly not in the interests of a cheating state to deliver evidence of non-compliance 'on a plate'. Even if a state agrees to give the Agency access, visits can be delayed until incriminating evidence has been removed or they can be managed to avoid the discovery of such evidence.

If a state refuses to give voluntary access then the Agency does have a formal legal remedy—special inspections. According to paragraph 73(b) of INFCIRC/153, it may instigate special inspections when 'information made available by the State, including explanations from the State and information obtained from routine inspections, is not adequate for the Agency to fulfil its responsibilities under [this] Agreement'.[23] Two questions need to be addressed. First, is the Agency allowed to request a special inspection for the purpose of verifying military R&D? And, second, what kind of evidence is the Agency allowed to employ when doing so?

The Agency's responsibilities under the safeguards agreement are 'the timely detection of diversion of significant quantities of *nuclear material* from peaceful nuclear activities to the manufacture of nuclear weapons or of other nuclear explosive devices or for purposes unknown'.[24] Special inspections may therefore be used to verify any activity involving nuclear material, whether or not it has been declared. This is a more significant power than it may first appear as many weaponization activities (for example, criticality experiments,[25] the fabrication of the pit[26] of a nuclear weapon, and the final assembly of a nuclear weapon) do involve nuclear material. The IAEA Board of Governors has asserted the Agency's right to request special inspections on 'rare occasions'.[27] In fact, the Agency has requested special inspections only twice in the past (in Romania and North Korea).

Disagreements on the use of special inspections focus on the case of weaponization activities that do not involve nuclear materials (such as theoretical studies, high-explosive tests and the preparations for a full nuclear test). Those who say that the Agency can inspect such activities, including former IAEA Director General Hans Blix,[28] argue that this kind of activity provides evidence that a state is intending to divert nuclear material. The current director general, Mohamed ElBaradei, has taken a more cautious approach, and has simply argued that 'the Agency's legal authority to investigate possible parallel weaponization activity is limited, absent some nexus linking the activity to nuclear material'.[29] While the current director general does not rule out the use of special inspections, he has not elaborated on when the legal authority would apply. As mentioned above, under paragraph 28 of INFCIRC/153, the IAEA is responsible for detecting the diversion of nuclear material. One interpretation of this provision is that the safeguards system should look for past and present diversions of nuclear material. In contrast, Blix's statement focuses on the intention to divert, that is, a suspected diversion set to happen in the future. If a special inspection can only be invoked by the Agency once a diversion has occurred, the organization's ability to act proactively would be seriously constrained.

Under paragraph 77 of the Comprehensive Safeguards Agreement, any disagreement on the need for special inspections should be resolved through the dispute resolution mechanism set out in paragraphs 21 and 22. This puts the onus of resolving the disagreement on the state concerned, since the state is the party that is required to initiate consultations. Following a request from the state, the IAEA Board of Governors is required to consider the issue. The inspected state must be invited by the Board to participate in its discussions. Although, in theory, the Board could take action after its discussion, any decision could be challenged by the state in an arbitral tribunal. Practically, therefore, the state has the means at its disposal to draw out the consultation process for a long time. Thus, an inspection, if and when it is actually approved, will be essentially meaningless.

There is, of course, a quicker route available. Paragraph 18 of the Comprehensive Safeguards Agreement charts the route to be taken if access is deemed 'essential and urgent' in order to ensure that nuclear material is not being diverted to a weapons programme. Such a finding can only be reached after a report by the director general and, in that event, the Board may call upon the state to take the required action without delay (irrespective of whether procedures for the settlement of a dispute have been invoked). If the state concerned does not heed the Board's call, the Board may take any of the steps outlined in Article XII.C of the IAEA Statute (which includes reporting the case to the United Nations Security Council for further action).

While Board discussions would not set any precedents, any discussions on the conditions for the use of special inspections by the IAEA Board of Governors would have relevance for future requests for special inspections.

Having established that special inspections can be used to inspect at least some types of weaponization activities, it is necessary to discuss the procedure for requesting them. According to paragraph 73(b) of INFCIRC/153 the information the IAEA is allowed to use in this regard is 'information made available by the state, including explanations from the State and information from routine inspections'. Thus, in the case of fuel cycle activities, if the Agency finds inconsistencies in a state's declaration, or if a state fails to fulfil its obligations under its safeguards agreements, the Agency can (after asking for further clarification) request a special inspection.

States, however, are not required to submit reports on military R&D. Neither is the Agency likely to gain any information about military R&D from routine inspections. If, therefore, 'information made available by the state' is the *only* source the Agency is allowed to use in requesting a special inspection, it is difficult to foresee the Agency ever being in a position to inspect suspected weaponization activities. However, the language of paragraph 73(b) does not preclude it from taking other information sources into account. Indeed, the Agency requested a special inspection in North Korea in 1993 on the basis of inconsistencies between satellite imagery supplied by the United States and North Korea's initial report (the Agency had first tried to resolve the inconsistency by asking for voluntary access).[30] It can be argued, therefore, that the Agency can use all the information sources it has at its disposal when requesting a special inspection, providing it first seeks further clarification from the state.

Access rights under an additional protocol

When INFCIRC/153 is the only safeguards agreement in force, the Agency can use special inspections to inspect weaponization activities which involve nuclear material. Whether it is entitled to inspect those that do not involve nuclear material is less clear. It is, therefore, important to ask whether the Agency has any additional, unambiguous verification rights in a state with an additional protocol in force.

Pursuant to the complementary access provisions of an additional protocol, the Agency has the right to inspect all places on a site. The term 'site' includes all places located in the same delimited area as a declared nuclear facility.[31] Complementary access provisions therefore give the Agency access to any weaponization activity—whether or not it involves nuclear material—that is based on a site.

In addition, Article 2.a.(i) of INFCIRC/540 requires states to declare any 'nuclear fuel cycle-related research and development activities not involving nuclear material'. One activity encompassed by this clause, 'any process or system development aspect for . . . nuclear fuel fabrication',[32] is highly relevant to weaponization as it would seem to include the development of equipment for fabricating the pit of a nuclear weapon.[33] The complementary access provisions of an additional protocol are sufficiently robust that, where an additional protocol is in force, the Agency has the right to inspect this equipment whether or not nuclear material is physically present.[34]

Are there other verification rights?

With the exception of various bilateral arrangements, it is Article III of the NPT that forms the basis of the current verification regime. Is it important to ask, therefore, whether any other verification rights and obligations can be derived from this article. There have been attempts to do that, but these attempts have not attracted a wide circle of supporters. Some of the arguments are quite obscure. For instance, ambassadors George Bunn and Roland Timerbaev, key NPT negotiators for the United States and the Soviet Union, have argued that the treaty itself provides the Agency with the authority to investigate any weaponization activity which involves 'the making, testing or procurement of a component intended for use in a nuclear weapon'.[35] The argument essentially builds on their assumption that the NPT carries more weight than the bilateral safeguards agreements it calls upon states to conclude with the IAEA. They point out that, according to Article III.1, obligations 'assumed with a view to preventing diversion' are to be verified. This wording suggests a verification regime going beyond material accountancy and other measures to detect the diversion of nuclear materials.

Their argument is related to the one that Blix has used to justify special inspections of sites where nuclear material is not present. It is argued that, since weaponization activities provide evidence of past, present or possibly future diversion (whether or not they involve nuclear material), then Article III.1 is broad enough to permit weaponization inspections. Bunn and Timerbaev's argument is far from universally accepted. In particular, the emphasis their argument places on the NPT—an instrument of general application—rather than the detailed and technical INFCIRC/153 has been criticized.[36] Indeed, their interpretation seemingly runs contrary to one predominant principle in international law—that specific law prevails over general law.[37]

What powers does the Agency have to obtain evidence that could be used to invoke inspections?

The importance of collecting information prior to instigating inspections of suspected weaponization activities was discussed above. There are many verification techniques the Agency could use or is already using to gather preliminary evidence—open source data, commercial satellite imagery and wide-area environmental monitoring, for example. The question of whether it is permitted to use a particular verification technique depends, to some extent, on the means in question. Given that there are a number of possible data sources and verification techniques the Agency could use, it makes sense to delay a detailed discussion until later, once these techniques and technologies have been identified and their use discussed.

It is important to note that, in addition to actively gathering evidence about weaponization, the IAEA may be given or even unintentionally 'come across' such evidence. Article VIII.A of its Statute allows member states to give the Agency 'information as would, in the judgement of the member, be helpful to the Agency'. Moreover, the activities currently undertaken by the Agency to search for clandestine fuel cycle activities may also yield evidence about weaponization activities, even if the Agency is not undertaking them for this purpose.

What experience does the Agency already have of verifying military research and development?

Many of the highest-profile IAEA investigations have involved the verification of military research and development. As discussed below, the countries inspected in this regard include Iran, Iraq, Libya and South Africa. Moreover, it can also be argued that, to some extent, the Agency is already looking for indicators of weaponization activities through some of its 'voluntary' activities (voluntary in the sense that they fall outside the core tasks mandated by INFCIRC/153 and INFCIRC/540).

In this section we examine the Agency's experience of verifying military research and development. There are two reasons for doing so.

- First, Agency practice may help to clarify grey areas in the Agency's mandate.
- Second, it is useful to identify what expertise the Agency already has to conduct weaponization inspections.

Specific investigations

The Agency has inspected military R&D in four high-profile cases—Iran, Iraq, Libya and South Africa. From the outset, it is important to note that each of these cases is unique and there are few solid conclusions that can be drawn from looking at them collectively. Table 1 summarizes their similarities and dissimilarities. Each of the cases is then discussed individually. Only the parts of the Agency's work that were relevant to verifying weaponization activities are touched upon. It should be noted that, in each case, the Agency was tasked with verifying fuel cycle activities as well. Indeed, this was arguably its primary function. In particular, the sources of the Agency's mandate to search for weaponization activities and the practical steps it took towards verifying military R&D are identified.

Table 1 Similarities/dissimilarities matrix for the cases of Iran, Iraq, Libya and South Africa

	What was the source of the Agency's mandate?	What was the nature of the access granted?	What was the state's perception of the Agency?	Did inspectors from nuclear weapon states play a lead role?	Was the issue resolved?
Iran	INFCIRC/153,[38] and INFCIRC/540[39]	Emphasis on voluntary access	Suspicious	No	Investigations ongoing
Iraq	INFCIRC/153[40] and UNSCR 687	Increasingly obstructionist (became cooperative 'when too late')	Suspicious	Yes	Investigations interrupted by use of force
Libya	INFCIRC/153[41] and INFCIRC/540[42]	Full access	Trustful	Yes	Investigations ongoing[43]
South Africa	INFCIRC/153[44]	Full access	Trustful	Yes	Yes

Note: UNSCR = UN Security Council Resolution.

Iran

The IAEA's ongoing activities in Iran, although primarily concerned with fuel cycle-related activities, have also involved enquiries into military research and development.[45] Specifically, over the past two years the Agency has investigated:

- a 15-page document, apparently supplied to Iran by the A. Q. Khan network, which describes procedures for the conversion of uranium hexafluoride (UF_6) to uranium metal and for the casting of uranium metal into hemispheres[46] (these processes are required to manufacture the pit of an implosion-type nuclear weapon);
- the 'Green Salt' project, a series of studies 'concerning the conversion of uranium dioxide [UO_2] into [uranium tetrafluoride] UF_4 (often referred to as "green salt")';[47]
- tests 'related to high explosives and the design of a missile re-entry vehicle, all of which could involve nuclear material and which appear to have administrative interconnections';[48]
- experiments involving polonium-210 and beryllium:[49] such experiments could have relevance to the design of an initiator. Neither polonium-210 nor its precursor bismuth-209 is classed as a nuclear material requiring safeguards;

- three 'defence-related' sites (Kolahdouz, Lavisan-Shian and Parchin) to search for 'equipment, materials and activities which have applications both in the conventional military area and in the civilian sphere as well as in the nuclear military area'.[50] Iran facilitated access to these sites on a voluntary basis.
  - The investigations at Lavisan related to alleged undeclared uranium enrichment and conversion activities.[51]
  - Those at Kolahdouz were to investigate open source reports of enrichment.[52]
  - The Agency has not announced in any detail the purpose of its investigations at Parchin but, on the basis of satellite imagery and the proximity of a high-explosive facility, it has been suggested that the Parchin facility is suitable for conducting hydrodynamic tests.[53]

Access to these sites was given to the Agency by Iran on a voluntary basis. Iran is a sui generis case. It cannot be argued that any new inspection precedents were set. It is worthwhile noting, however, that the Agency clearly did not feel bound to restrict its investigations solely to facilities at which nuclear material was present. First, the investigations into the 15-page document indicate that the Agency is prepared to investigate the development of technology for fabricating the pit of a nuclear weapon, even in the absence of nuclear material. Second, the investigations into the polonium-210 experiments and those into the Parchin facility (if it is confirmed that the Agency was indeed attempting to find evidence of high-explosive test facilities at Parchin) indicate that the Agency is willing to investigate weaponization activities even when no nuclear material is present.

The IAEA's activities in Iran are likely to generate new thinking on the operation of safeguards, especially in respect to how to address weaponization-related R&D.

Iraq

Iraq's Comprehensive Safeguards Agreement with the IAEA entered into force in 1972. However, the Agency failed to detect Iraq's nuclear weapons programme. Following the first Gulf War, the UN Security Council adopted Resolution 687 which tasked the IAEA with the 'destruction, removal or rendering harmless' of all parts of Iraq's nuclear weapons programme.[54] It further demanded that Iraq accept 'immediate on-site inspections' at any location requested by the Agency.

The Agency's first task was to understand the full extent of Iraq's programme. In September 1991 the Agency Action Team seized documents which proved the existence of a project, code-named Petrochemical Three, to manufacture an HEU-fuelled implosion device.[55] Using these documents as a starting point the Agency was able to map out much of Iraq's programme, to remove equipment and to destroy facilities.[56] In April and May 1992, for example, it confiscated isostatic presses, machine tools and vacuum pumps from Al Atheer (Iraq's principal high-explosives facility).[57] At the same facility, an explosion chamber was destroyed by cutting it with torches and a high-explosives test bunker was filled with concrete and scrap metal.[58] Agency investigations were significantly aided by information provided by member states.[59]

Until 1995 Iraq was very obstructive of the Agency's work: its declarations were frequently incomplete, equipment was hidden, and attempts were made to prevent the Agency from gaining access to key facilities and personnel. Just after the documents mentioned above were collected, for example, Iraq forcibly confiscated them and detained the inspection team in a parking lot for four days.[60] Nevertheless, in spite of these difficulties, by early 1995 the Agency was in a position to declare that, with the exception of the period June 1990 to January 1991, it had built up a good understanding of Iraq's weaponization efforts.[61] Subsequent investigations proved this claim to be correct.

From the defection of Gen. Hussein Kamel, head of the Iraqi Ministry of Industry and Military Industrialization (and a son-in-law of Saddam Hussein) in August 1995, for a period of about two years, Iraq became much more cooperative. In particular, immediately following Kamel's defection Iraq surrendered the 'chicken farm documents',[62] many of which related to Iraq's weaponization efforts in the second half of 1990. These documents revealed details about the crash programme and also about Iraq's progress in weapons design and the casting and machining of uranium.[63] On the basis of this information, the IAEA discovered and removed some of the most sensitive components related to Iraq's weapons programme, including a cylindrical initiator, a wave front measurement device and a 32-point electrical distributor for a firing set.[64] Tensions between the UN monitoring teams and Iraq began to rise again in 1997, culminating ultimately in the withdrawal of inspectors in 1998 (prior to Operation Desert Fox).[65] At that stage the Agency had a few relatively minor, but still unresolved, questions about Iraq's nuclear programme, including its weaponization activities.[66] With the difficulty of verifying small-scale weaponization activities exacerbated by the lack of access, the Agency stated in 1999 that 'verification measures cannot guarantee detection of readily concealable or disguisable activities, such as computer-based weaponization studies, [or] explosives experimentation'.[67] Nevertheless, Agency investigations[68] just prior to the second Gulf War and the work of the Iraq Survey Group[69] just afterwards found no evidence that Iraq had restarted its nuclear programme after 1998.

There are three lessons to be drawn from the Agency's experience in Iraq.

- First, with a comprehensive mandate and strong international backing, the Agency is able to dismantle a weaponization programme even when its efforts are hindered by a highly uncooperative state. Such a process is, however, likely to be slow. Resolution 687 originally gave the Agency 45 days to complete its investigations; in reality, the investigations were not complete in 1998 when inspectors were withdrawn after over seven years of work.
- Second, analysis of the Agency's work in Iraq has demonstrated that its operations are significantly enhanced by an experienced inspectorate. In 1993, for example, its efforts were hampered by a major turnover of personnel.[70] Following that experience the Agency implemented new procedures—both technical and organizational—to ensure that institutional knowledge was not lost. These were sufficient to allow the Agency to 'hit the ground running' when it recommenced its operations in November 2002.
- Third, through its work in Iraq, the Agency has gained experience of verifying every aspect of a sophisticated, advanced and well-funded weaponization programme. If it can be preserved (and the Iraq Nuclear Verification Office has yet to be disbanded) this kind of knowledge would be invaluable in any future programme of verifying military research and development.[71]

South Africa

South Africa[72] acceded to the NPT in 1991 and, following the conclusion of an INFCIRC/153-type safeguards agreement with the IAEA, inspectors began the process of verifying its nuclear activities. Although South Africa declared the HEU used in its nuclear weapons, it did not officially admit their existence until 1993. Before 1993, the Agency focused largely on the fuel cycle as it attempted to verify the correctness of South Africa's initial declaration. Its efforts to probe the extent of South Africa's weaponization efforts were rather limited but did include environmental sampling on the basis of information provided by member states. After 1993, the Agency was tasked with verifying that South Africa's nuclear weapons programme had been completely dismantled. Its remit was based on its safeguards agreement and a promise of full cooperation with the Agency. The latter was given briefings about the South African programme as well as access to technical staff and documentation. On the basis of this information it was able to map out all the stages in South Africa's weaponization programme, including its dismantlement. Activities undertaken by the Agency to ensure that the dismantlement was complete included:

- visual inspections of destroyed and partially destroyed non-nuclear components from nuclear weapons;
- inspections of facilities involved in the weapons programme; and
- verification of the process for rendering test shafts useless.

The Agency was able to verify the dismantlement of South Africa's nuclear weapons programme within two years.

Libya

The IAEA started verifying Libya's civilian nuclear programme in 1980, following the conclusion of an INFCIRC/153-type safeguards agreement.[73] From then until 2003, when Libya announced its decision to renounce weapons of mass destruction, the Agency failed to find any evidence of Libya's clandestine nuclear weapons programme. The Libyan case is most interesting from a legal point of view because the Agency's right to inspect Libya's weapons programme was contested not by the Libyans—who promised to give full cooperation and to act as if an additional protocol were in force until one was ratified—but by the United Kingdom and the United States, which wanted to lead the verification process themselves. In the end, a joint initiative was agreed upon whereby the Agency would 'verify that Libya's programme is properly dismantled, while the Americans and Britons would physically destroy the capabilities'.[74]

Libya's weaponization programme was still at an embryonic stage when it was terminated in 2003. Libya admitted that it had purchased some documents on weapons design from the A. Q. Khan network, and handed these to documents to the Agency.[75] To avoid divulging proliferation-sensitive information, only security-cleared inspectors from nuclear weapon states (NWS) were permitted to view these documents.[76] Libya claimed that it had taken no further practical steps towards manufacturing a weapon because it lacked the relevant expertise.[77] To verify this claim the Agency identified and inspected a number of facilities which, from a technical perspective, could have been involved with weaponization.[78] It also analysed information obtained from its ongoing investigations into the A. Q. Khan network. Although the Agency could find no evidence to contradict Libya's claim about its weaponization efforts, it has requested 'additional information'.[79]

Conclusions drawn from the cases of South Africa and Libya

Given that both South Africa and Libya promised full cooperation with the IAEA in its efforts to investigate their weapons programmes (in addition to any safeguards agreements) it is difficult to argue convincingly that either of these cases sets a verification precedent. What the South African and Libyan examples do demonstrate is the Agency's ability to verify military R&D quickly and effectively when the host state is cooperative. The Agency must have gained much valuable experience of verifying weaponization activities through its work in South Africa. However, this work was carried out almost 15 years ago and it is therefore very doubtful whether that expertise could be harnessed today. Moreover, some of the lessons learnt in South Africa may be slightly singular anyway because of the unusual nature of its weapons programme (because of South Africa's very particular strategy for using nuclear weapons it developed gun-type devices with no initiators—in contrast, all other proliferators have focused on implosion technology).[80] The Agency would have gained some useful experience in Libya, although less than in South Africa (or Iraq, for that matter) because Libya's weapons programme was much less advanced. Finally, it is important to note that the Agency was greatly aided in both cases by weaponization experts from NWS.

Other relevant IAEA activities

It is also relevant to note that the Agency is currently trying to enhance its ability to detect materials diversion and illicit fuel cycle activities.[81] Some of the methods it has recently adopted may be yielding information about weaponization activities as well. These include:

- investigating black market nuclear supply chains through, for example, the Agency's Illicit Trafficking Database;[82]
- increasing the use of satellite imagery (including ground-penetrating radar) from national technical means (NTM) and commercial sources; and
- improving access to scientific literature in languages other than English.

In addition, training courses for inspectors now include modules on 'proliferation indicators' and 'advanced observation'.[83] It is possible that these courses discuss indicators of weaponization.

What is to be detected? Indicators of weaponization

General principles

The principles underlying a search for clandestine weaponization activities are similar to those the Agency uses in looking for clandestine fuel cycle activities. The IAEA attempts to verify the completeness, as well as the correctness, of a state's declaration about its fuel cycle activities. The idea is straightforward: having used a state's declaration to acquire a picture of the declared nuclear fuel cycle activities in a state, the Agency attempts to identify whether there are any significant quantities of nuclear material that have not been accounted for by looking for indicators of clandestine nuclear activities.[84] For instance, the Agency examines satellite imagery in an attempt to identify any undeclared nuclear facilities. It also analyses open source scientific literature for evidence of experiments that have been performed with undeclared nuclear materials. The Agency undertakes this kind of process every time it produces a state evaluation report. The goal is to announce in the annual Safeguards Implementation Report whether it has found indications of any undeclared nuclear activities being carried out in the territory of any of the states it monitors.

To verify that no weaponization activities are being conducted is more difficult. As noted above, no state is likely to declare its weaponization activities and states' reports on their fuel cycle activities are unlikely to be of much help in verifying military R&D. Since the IAEA is lacking an important component of the verification regime (i.e. information submitted from member states), verification activities would have to commence on vague, often incorrect and most definitely incomplete information. In fact, the Agency would have to base its investigations on information collected through its own means—or information collected by national intelligence, voluntarily submitted by member states.

One similarity with the present safeguards regime, however, is that the Agency could search for a clandestine weaponization programme by looking for certain characteristic indicators[85]—equipment imported from abroad, substances in the effluent of suspect laboratories and changes in the structure of the scientific community, for example.[86] The principal challenge associated with searching for weaponization is that very few of these indicators are unambiguous. It is true that certain components are relevant only to nuclear weapons (hemispheres of metallic plutonium, initiators and explosive lenses, for instance). However, searching for these components directly is unlikely to be a fruitful strategy since they can easily be hidden or destroyed. Instead, it is better to search for evidence of activities in which these components are developed, manufactured and tested. Unfortunately, the indicators for such activities—typically items of equipment and materials—are generally ambiguous. Almost every piece of equipment used to manufacture a nuclear weapon has at least one other, legitimate, application. In fact, there is only one piece of equipment that is used solely for weaponization—data sets for the equation of state of plutonium and uranium at extremely high temperatures and pressures.[87] These data sets, being nothing more than computer files, are in practice almost impossible to identify.

Similarly, there is no material that is a completely unambiguous indicator of weaponization. Metallic plutonium comes closest but it is used in some types of submarine reactors (although currently all such reactors are in the hands of NWS). Similarly, few states would have a legitimate purpose for possessing metallic HEU. All other materials used in the manufacture of nuclear weapons have a number of other legitimate applications. It therefore does not seem plausible to search for clandestine weaponization activities by drawing up a 'trigger list' of single-use items employed in weaponization, as some observers have suggested.

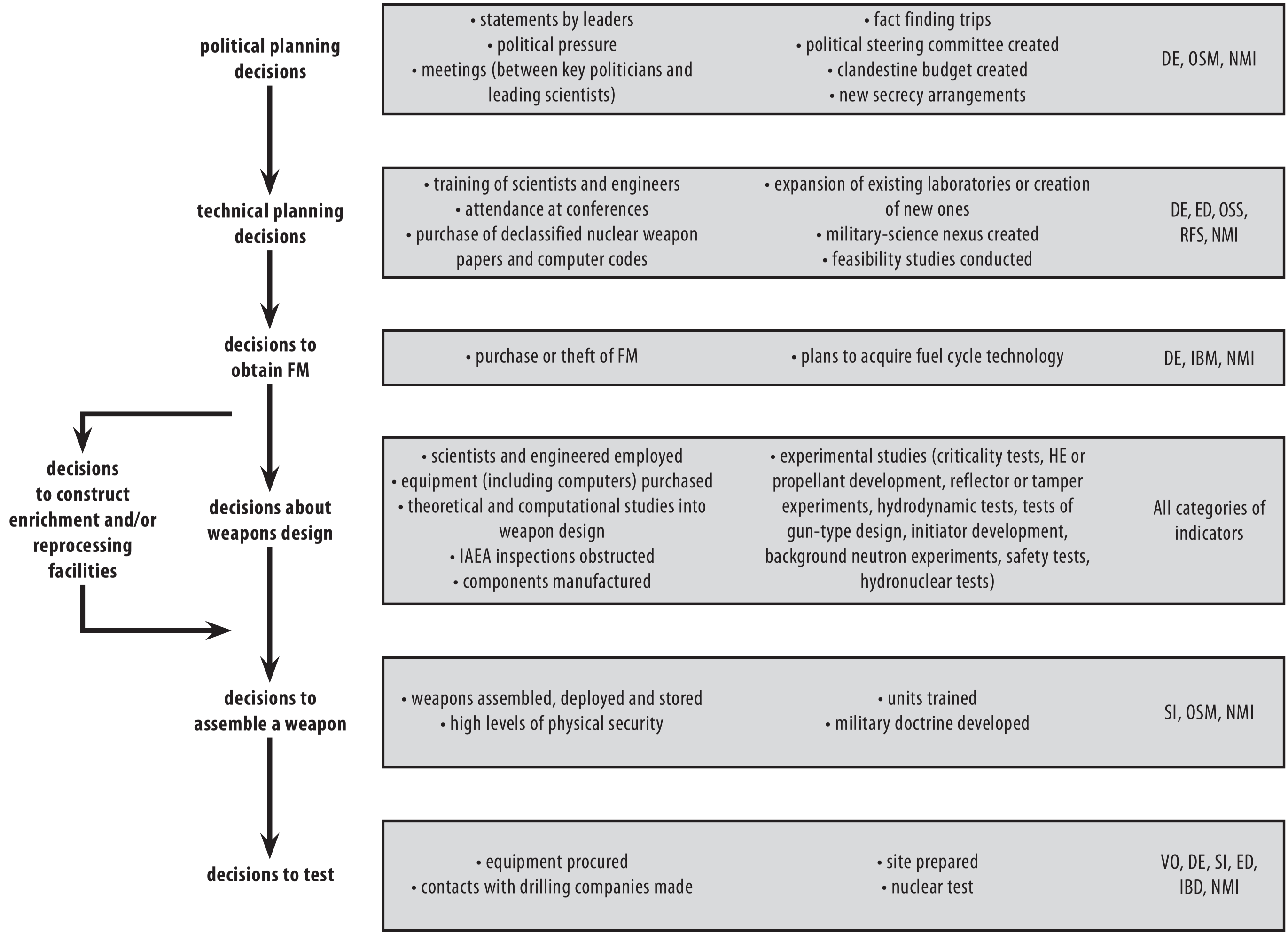
Rather than relying on unambiguous indicators, therefore, searches for weaponization must inevitably look for correlations and associations of ambiguous indicators—the simultaneous import of a number of dual-use items or the appearance of a number of substances in the effluent from an industrial plant, for instance. It is important to note that this kind of evidence is circumstantial. It is also 'statistical' in the sense that, in most cases, it would be suggestive of, rather than definitively prove, the existence of a weaponization programme.

In the following section, a number of weaponization activities and their associated indicators are identified.

Weaponization activities and indicators

In 1966, during NPT negotiations, Ambassador Alva Myrdal of Sweden pointed out that the manufacture of a nuclear weapon is a process rather than a single event.[88] Looking at the situation in retrospect, it seems likely that Ambassador Myrdal based her description on discussions taking place within the Swedish government at around that time on the possible acquisition of an independent nuclear deterrent.[89] Her observation is also interesting from a verification standpoint. Since the manufacture of a device would require a chain of decisions,

Figure 2 The Myrdal Chain



Note: As pointed out by Ambassador Alva Mydral, the manufacture of a nuclear weapon is not a single event but a series of interrelated decisions. That decision chain is shown on the left of the figure. For each decision, examples of the resulting physical evidence and possible verification techniques are shown in the centre and right, respectively. **Key:** IAEA = International Atomic Energy Agency; HE = high explosive; DE = documentary evidence; OSM = open source media reports; NMI = national means of intelligence; ED = export data; OSS = open source scientific literature; RFS = reports from foreign scientists; IBM = investigations into the black market; SI = high-resolution satellite imagery; VO = visual observations; IBD = international banking data.

each link in the chain—each event—is likely to produce physical evidence. For instance, the political decision to start conceptualizing future research and development may be reflected in minutes from a meeting. Later on, orders and budgets are drafted and circulated. Since the nuclear programme needs a physical location, buildings are acquired or constructed. Security may be put in place. Equipment is purchased, transported and installed. All these activities are bound to leave a paper trail or other physical evidence. At the end of the chain, the decision to conduct a nuclear test results in an explosion that can, in turn, be detected by the monitoring equipment of the International Monitoring System.

A useful exercise is to envision this chain of decisions, establish which physical evidence each decision is likely to produce and then identify which monitoring or verification methodologies and technologies can be used to scoop up that evidence. Examining nuclear weapons acquisition in this way is useful for obtaining conceptual clarity. Figure 2 summarizes the results. The left-hand side of figure 2 shows an adapted version of this 'Myrdal Chain' of events. This list is published for illustrative purposes only, and it should be borne in mind that the order and nature of the decisions will vary from state to state. It is significantly easier, for example, for a state with some kind of fuel cycle technology to manufacture a nuclear weapon than a state with no experience of enrichment or reprocessing.

Examples of the physical evidence which might result from the decisions taken in the chain are shown in the centre of figure 2 (note that the indicators associated with enrichment and reprocessing have been omitted as they are already well documented and beyond the scope of this paper). The figure is intended to highlight the range of different activities and indicators associated with weaponization. It does not aim to be comprehensive. Moreover, physical evidence is only useful if there are means available to detect, collect and assess it. Table 2, therefore, lists a number verification techniques (some of which are not currently at the Agency's disposal).[90] These methods range from visual observations made by inspectors on the ground to remote monitoring techniques. The methods listed also include 'software-oriented' means of verification, such as the collection, collation and analysis of export and import data. The right-hand side of figure 2 shows some of the methods which could be useful at each stage of the Myrdal Chain.

The key indicators of weaponization—those which are most useful in practice—are summarized in table 3.[91] In the first column, seven activities associated with weaponization are listed. The next three columns list indicators for these activities in the form of equipment that must be procured,[92] substances that may be released into the environment as part of effluent, and distinctive external features. This table is not intended to be exhaustive. Not only are there many more activities associated with weaponization than are listed in it, but there are also more indicators than those listed. The activities enumerated were chosen on the grounds that they are unambiguously associated with weaponization *and* have distinctive indicators. Equipment, effluent and external features were chosen as categories of indicators on the basis of practicality. Clearly, an internal inspection of a laboratory in which an initiator is being developed could provide stronger evidence of weaponization than any of the indicators listed in table 3 (indeed, such inspections are discussed below); however, evidence of weaponization is required before such inspections could be requested. The indicators listed in table 3 are therefore designed to assist in gathering such evidence.

Table 2 Verification techniques and their uses

	Data source	Equipment	Effluent	External physical features	Other
Inspections	Visual observations (VO)	✓		✓	✓
	Environmental sampling (wide-area or site-specific)		✓		
	Plant stress		✓		
	Documentary evidence (DE)	✓	✓	✓	✓
Remote monitoring	High-resolution satellite imagery (national means or commercial) (SI)			✓	
	Hyperspectral satellite imaging		✓		
	Airborne air sampling		✓		
	Patterns of electricity use	✓			
Export and financial data	Export data (including refusals) (ED)	✓			
	International banking data (IBD)	✓			✓
	Investigations into the black market (IBM)	✓			✓
Open source data	Media reports (OSM)				✓
	Scientific literature (OSS)				✓
	Reports from foreign scientists (RFS)				✓
Intelligence	National means of intelligence (NMI)	✓	✓	✓	✓

Note: The abbreviations introduced in the second column are those used in figure 2.

Table 3 Selected weaponization activities and their indicators

Activity	Equipment	Effluent	External physical features[e]
Fabrication of fissile pit	Glove boxes or hot caves with special ventilation systems; remote manipulators; remote loaded environmentally-controlled furnaces (plasma, e-beam, induction or electric); NC multi-axis turning, grinding, milling or combination machines; NC non-wire electro-discharge machines; NC coordinate measuring machines (linear, angular or combination)[a]	WGPu, plutonium oxide, tantalum, magnesium oxide, aluminium, graphite, calcium fluoride (for a plutonium pit) HEU, uranium oxide, graphite, zirconium silicate, magnesium silicate (for a uranium pit)	
HE development	Hot isostatic presses; NC multi-axis milling machines; firing sets (e.g. exploding bridge wire detonators)	Suitable HE (e.g. baratol, cyclotol, RDX), especially if not previously manufactured by the state concerned	Expansion of an existing ordnance facility; lightning protection
Hydrodynamic testing	Vin domes; high speed oscilloscopes and recording devices; flash X-ray generators; flash X-ray recording systems (photographic, digital or analogue); framing or streak cameras; explosion containment vessels[c]	Depleted uranium, natural uranium, 'plutonium stimulant', tungsten, beryllium	Test pad; housing for equipment; sand bags; exclusion zone, physical effects (visual and auditory) of HE tests; control room (possibly underground) away from test site
Fissile material experiments (including initiator development)	High-speed neutron counters; neutron generator tubes; hot cells or glove boxes	HEU, WGPu, beryllium, plutonium-238[d], polonium-208[d], polonium-210[d], actinium-227[d], radium-226[d]	Heavily shielded/underground laboratory; laboratory physically isolated from control room
Reliability testing	Electrodynamic vibration test systems; vibration thrusters		Tests of new designs of freefall bombs or missiles
Preparations for a full nuclear test[b]	Drilling rigs; neutron, X-ray and gamma ray detectors, scattering stations and cameras; streak or framing cameras; high-speed oscilloscopes; coaxial and fibre-optic cables		Mining operations; large-diameter pipes laid out; road construction; remote site
Weapons assembly and preparations for the storage and deployment of weapons			Especially high levels of security; new patterns of military activity (e.g. aircraft practising for nuclear weapon delivery)

Key: HE = high explosive; NC = numerically controlled; WGPu = weapons grade plutonium; HEU = high enriched uranium.

(a) The list given here relates to manufacture of a plutonium pit. Fewer items of less sophistication are needed for the fabrication of a uranium pit (although isostatic presses could potentially be useful for working with uranium). The core of a gun-type device can be manufactured using much more primitive equipment.

(b) The International Monitoring System set up under the 1996 Comprehensive Test Ban Treaty would almost certainly detect the test itself. The indicators given in this table therefore relate only to the preparations for a test.

(c) Used only in small-scale hydrodynamic tests, particularly those which involve subcritical amounts of nuclear material (hydronuclear tests).

(d) The production of these materials is also a useful indicator, but one which the Agency is already likely to identify given it takes place in a reactor. In 2004, for example, the Agency discovered that Iran was irradiating bismuth-209 to produce polonium-210.

(e) Every facility used as part of a weaponization programme is expected to have high levels of physical security.

To complete the picture, table 2 shows which verification techniques could potentially yield information about equipment, effluent and external physical features. Some of the verification techniques could produce evidence that does not fit into these three categories, such as changes in the structure of the scientific community. This kind of evidence is shown in the column marked 'other'.

As mentioned above, almost all the indicators listed in table 3 are, by themselves, ambiguous. It is correlations that are important. For instance, a concerted purchase of specially filtered glove boxes, numerically-controlled milling machines and environmentally-controlled induction furnaces would provide much stronger evidence for plutonium pit fabrication than the purchase of any one item by itself. Naturally, circumstantial evidence of this kind would be perceived as more substantive if it could be proved that the items were delivered to a single facility. Circumstantial evidence would become almost concrete if tantalum, say, were present in the effluent from that facility.

Evidence proving the existence of a clandestine weaponization programme beyond any doubt would be hard to come by. However, several pieces of concrete evidence joined together could bring the standard of proof to a high level (for example, scientists being secretly employed, the purchase of equipment suitable for fabricating the pit of a nuclear weapon and increased physical security around a suspect weapons assembly facility).

The fact that weaponization activities would typically be spread over a number of sites creates opportunities for the verification process because there are more possibilities for detecting a facility involved in weaponization. However, since the indicators would be more dispersed it would make it harder to detect correlations.

Given the nature of the evidence—correlated indicators from multiple data sources about a variety of locations—effective data management would be a significant challenge. As mentioned above, however, there are similarities between this task and the Agency's current job of collating data to verify the absence of undeclared fuel cycle activities in a state.[93] The Agency should be well placed, therefore, to build on its existing expertise and develop a data management system for weaponization indicators. In constructing a data management system, it would have to decide which of the verification techniques listed in table 2 it wished to employ. Cost, technical and political considerations would all come into play. National intelligence data, for example, would cost the Agency very little and could potentially yield a great deal of information; but their use would be highly controversial. A second consideration would be how to weight different indicators. The purchase of a highly accurate numerically-controlled six-axis milling machine would be a stronger indicator of weaponization than the purchase of a large quantity of coaxial cables, for example. It would therefore be highly desirable to develop a quantitative model to take such weightings into account. This would involve creating a graduated scale where a piece of equipment, say, is no longer classified simply as single-use or dual-use but is scored according to the *likelihood* that it will be used in weaponization.

Currently, fuel cycle technology is often classified as either single-use (if its only known applications are in the nuclear fuel cycle) or dual-use (if it has other uses as well). It is not particularly useful to apply this classification scheme to weaponization because, as argued above, almost all technology used in weaponization is dual-use. Moreover, this classification scheme suffers because some items of equipment are 'more dual-use' than others. Thus, instead of using a single-use/dual-use classification scheme, it might make sense to employ a graduated scale. At one end of the scale would be 'completely' dual-use equipment, such as computers, which have many more non-nuclear uses than nuclear uses. At the other end would be 'completely' single-use equipment such as reactor vessels (in the case of fuel cycle technology) or equation of state data sets for plutonium under extreme temperature and pressure (in the case of weaponization) that only have nuclear applications. Other equipment would fit somewhere between these extremes. It seems both possible and desirable to quantify a graduated scale. It is, however, beyond the scope of this paper to propose an appropriate algorithm.

Avoiding false accusations

Because almost every item of equipment used in a weaponization programme has other legitimate uses, there is the real danger of states being falsely accused of conducting a clandestine weaponization programme. Japan and Germany, for instance, have either imported or manufactured almost every item of equipment in table 3. Both, however, have impeccable non-proliferation credentials and there is no suggestion that either is intending to manufacture a nuclear weapon. Rather, they are highly industrialized nations which use the equipment listed in table 3 for legitimate purposes.

One possible solution would be to take non-proliferation credentials into account when looking for weaponization indicators. This solution is desirable from a practical point of view. Politically, however, such an approach would be highly undesirable as it would leave the IAEA open to accusations of bias and might lead some states to be less cooperative when dealing with it. Indeed, the Agency is currently very careful to be seen as impartial in the way it applies safeguards.

Instead, a more acceptable solution is required—one that allows the Agency to look for evidence of clandestine weaponization activities in all states, including highly developed ones, without the danger of false accusations. Such a system could be based around two principles. First, context must be considered when analysing information about items of equipment. That is, it is necessary to assess, based on information about a state's industrial and scientific infrastructure, whether the country's acknowledged industrial base is advanced enough to be able to use a particular item of equipment, before it is possible to determine whether that equipment is being used for legitimate purposes. Second, it is important that a conclusion about the existence of a clandestine weaponization programme is not made purely on the basis of data about equipment. Conclusions must be corroborated with other independent indicators, such as the presence of certain materials in the effluent of suspect facilities or the external features of those facilities.

To what extent is past experience relevant to the future?

Table 3 is based on the weapons programmes of the NWS, the United Kingdom and the United States in particular. It is important to ask to what extent those experiences might be relevant to future proliferators. At one level, any weapons programme is constrained by fundamental considerations. Among these are scientific, engineering and military factors. Because of these factors there are some activities that any future weapons programme would almost certainly involve—for example, experiments to characterize the properties of fissile material, the fabrication of components (such as the fissile core and initiator[94]), the final assembly of weapons and preparations for their storage. At another level, the scientists engaged on such a weapons programme would probably want to conduct experiments that, while technically unnecessary, would help build confidence in their design. For this reason it is likely that some kind of safety and reliability testing would be undertaken. There are, therefore, likely to be many 'strategic' similarities between future weapons programmes and those of the past.

At the same time there are likely to be some strategic differences as well. All five NWS carried out full-scale tests of their first nuclear weapons, for example. This is now generally regarded as unnecessary (although there may be political or scientific reasons why it is desirable, in which case preparations for a test might be observable). Similarly, high-explosive development and hydrodynamic tests would only be required if a state decided to develop an implosion device. The equivalent processes in the development of a gun-type weapon (the development of propellant and the firing of test shots) are not listed in table 3 as they would be extremely difficult to detect.

In addition to these strategic differences between weapons programmes, it is natural to assume that there will be many, smaller 'tactical' differences, particularly in the choice of materials and equipment. This assumption is probably correct unless a state decides to model its programme on one from the past. Investigations into Iraq's weapons programme, for example, have revealed that 'Manhattan Project documents and information were very useful to Iraq in overcoming technical obstacles, particularly in its EMIS program'.[95] In this case there may be many similarities between future and past programmes at both a strategic and a tactical level. Table 3 can therefore only be indicative.

Case study: discovery of hydrodynamic tests

Table 3 does no more than summarize the indicators associated with a selected set of weaponization activities. Through a careful examination of each activity, it is possible to give more detail about the nature of the indicators and identify others which do not necessarily fit into the simple classification scheme used in the table. As an example, it is instructive to consider hydrodynamic tests (which potentially provide some of the best indicators of weaponization) as a more in-depth case study. A second reason for presenting a case study of this kind is that it can be used to highlight the differences and similarities between weapons programmes. As discussed above, it is important to recognize that there will almost certainly be differences, especially in the detail, between future weapons programmes and those of the past. A discussion of hydrodynamic tests offers the opportunity to analyse the scale of these potential differences and to identify potential similarities.

Even though a gun-type device is technically simpler, an implosion device is likely to be more desirable to a potential proliferator. The latter uses less fissile material, is smaller (and therefore easier to deliver) and typically has a higher yield.[96] In an implosion device a subcritical mass of fissile material (typically spherical) is driven to criticality by compressing it with high-explosive charges known as explosive lenses.[97] To maintain a high density of neutrons in the core, the pit is normally surrounded by a reflector (such as beryllium) or a tamper (such as tungsten, natural uranium or depleted uranium). The development of explosive lenses is usually considered to be the most challenging part of the weaponization process. An appropriate design, carefully manufactured lenses and the ability to detonate multiple charges almost simultaneously are all required.

This high level of theoretical complexity means that experiments, known as hydrodynamic tests, are very likely to be an integral part of the design process. Hydrodynamic tests are also useful for assessing the safety and reliability of existing designs.[98] In hydrodynamic tests the behaviour of the explosive lenses is studied by replacing the fissile pit with a 'simulant' that has similar physical properties. The choice of simulant depends upon the purpose of the test. Natural or depleted uranium is often used to simulate HEU.[99] Tantalum, lead and depleted uranium are all used to simulate plutonium.[100] For more accurate simulations of plutonium, special alloys have been developed. No information is publicly available on the composition of these alloys but they are unlikely to have any other application. With this exception, therefore, information about simulants is widely available in the public domain. It therefore seems unlikely that a new proliferator would go to the trouble of developing new simulants. This possibility, however, cannot be ruled out.

During the early stages of weapons development, small-scale prototype devices are likely to be tested. It is possible to conduct these experiments indoors. The Hydrodynamics Facility at Britain's Atomic Weapons Establishment (AWE), which conducts hydrodynamic tests to ensure the safety and reliability of British nuclear warheads, uses chambers which 'have internal volumes of the order of 1000 m^3, with armour plated walls and ceilings that are constructed of reinforced concrete some 0.6 m thick'.[101] Although some kind of specialized facility would be necessary for small-scale hydrodynamic tests (and specialized equipment used outdoors might suffice), the development of a primitive nuclear device would not require a facility as large or sophisticated as the British one. Nonetheless, the British facility may provide a useful guide. It suggests that it might be possible to detect a facility used for hydrodynamic tests by satellite imagery; evidence of its internal structure might even be visible during construction. In addition, for the few tests carried out in the United Kingdom that do involve fissile material (in subcritical amounts),[102] 'leak-tight spherical vessels, approximately one metre in diameter, made of thick, submarine quality steel'[103] are used to contain the explosion. A potential proliferator might attempt to acquire such vessels (described as 'explosion containment vessels' in table 3), although only if enough fissile material were available for such a test.

In addition to small-scale tests, it is necessary to carry out full-scale hydrodynamic tests at various points in the development process. Because of the quantity of high explosive involved, these tests are almost certain to be conducted in the open air.[104] There is likely to be an exclusion zone surrounding the test site.[105] American test sites typically consist of a concrete pad with housing for equipment on either side.[106] Satellite imagery could be used to identify suspect sites, if they follow this model. It should be noted, however, that it is certainly possible, if somewhat less convenient, to conduct tests 'in a field' without a test pad or housing for equipment. For the state, it would be convenient rather than necessary to base activities at a pre-existing ordnance facility. Hence, focusing on these facilities would be sensible, but a wider search may be necessary.

If the proliferator is to obtain useful data from a hydrodynamic test—full-scale or small-scale—it also needs to procure items listed in table 3.[107] Once again, it seems very unlikely—although not totally impossible—that a future proliferator would attempt to develop new methods for monitoring hydrodynamic tests. Analysis of import and export data is therefore useful for the purposes of detecting test preparations. And, as discussed in the next section, open source literature might also yield evidence that an appropriate body of scientific expertise was being assembled at a single facility.

The most dramatic indicators associated with outdoor experiments would be the tests themselves.[108] Just before a test, warning klaxons are likely to be sounded. The noise created by detonating a large quantity of high explosive is also far from insignificant. If natural or depleted uranium were used as a simulant, bright 'streamers' would be visible as metal expelled from the shot ignited. In the short term, damage to the surrounding flora might be visible. Given the short-lived nature of these indicators, it can be difficult to detect them. Interviews with people living near possible test sites could be useful in uncovering evidence of tests. Moreover, once a suspect facility had been identified it might be possible to monitor it using a satellite in the hope of detecting a hydrodynamic test.[109]

Outdoor tests would inevitably scatter fragments of the simulant and tamper or reflector (mixed with traces of explosive) over the test site and its surroundings. Although it would be possible for the tester to collect much of this material (indeed, it would probably be desirable to do so in order that expensive materials can be reused) tiny amounts would be likely to remain. Trace amounts might even be absorbed by plants. Given that modern environmental sampling methods can be used to detect microgram quantities of materials,[110] it might be possible to use location-specific or wide-area environmental monitoring—if a suspect test site had not been identified before a test was carried out—to detect minute amounts of the materials used in a hydrodynamic test even some time after it had been completed. Even by themselves, the three materials used in hydrodynamic tests (simulant, tamper or reflector and high explosive) are fairly distinctive. The detection of all three together would be extremely characteristic.

For this reason, although environmental monitoring is expensive, it has the potential to produce particularly compelling evidence of hydrodynamic testing. The feasibility of this idea ultimately depends upon how far material is spread by a hydrodynamic test.[111] Specifically, if there is a significant amount of vaporization during a test, then traces of re-condensed material may be found much further from the test site than the material which is directly scattered by the explosion. In principle, it should be straightforward to determine the efficacy of detecting hydrodynamic tests with environmental monitoring by computer models and experimental tests.

The use of conventional verification techniques

Thus far the discussion of the technical aspects of verifying military R&D has focused on identifying weaponization indicators rather than on the use of verification techniques to detect them. In this section and the next, relevant verification techniques are discussed in more depth with the aim of sketching out a strategy for searching for weaponization activities. In this section 'conventional' verification techniques are considered. These include all verification techniques except for the analysis of open source scientific literature, which is the subject of the following section.

Monitoring for a weaponization programme

Given the small-scale nature of many weaponization activities, the very hardest stage of detecting a weaponization programme is likely to be the first. There are literally millions of industrial and scientific facilities in the world. It would be both hopelessly inefficient and politically undesirable for the IAEA to pick facilities at random in an attempt to verify their operations. Instead, evidence of clandestine weaponization activities would, in the first instance, be likely to come from one of three sources—information provided by a member state; a 'software-based' analysis of relevant information (such as data on exports); and Agency investigations into a state's fuel cycle activities.

The potential difficulties associated with the IAEA receiving information from member states are political in nature.[112] This is especially true where intelligence data are concerned. In a politically sensitive situation it would be hard for the Agency to act on the basis of intelligence without being seen to legitimize intelligence-gathering activities. The Agency would also be left open to accusations of collusion with the intelligence services of the member state that provided the information. Moreover, it would be easy to dispute the veracity of intelligence data, especially if the Agency had been forbidden by the provider from making the data public. For these reasons, there would clearly be advantages in member states giving the Agency commercially available information which could be made public, even if these data were ultimately the result of an intelligence operation. Vetted intelligence data would probably be best treated as a 'tip-off' for use in guiding the Agency's own investigations, rather than as direct evidence of a clandestine weaponization programme.

Software-based analytical techniques may also be of use at this early stage. One such technique, based on open source scientific literature, is discussed below. Data on exports could also be useful. The IAEA currently uses information on exports as one means for identifying clandestine fuel cycle activities. Similarly data on the export of equipment and materials used in weaponization could be useful for identifying clandestine weaponization activities. One difficultly is that the items concerned are not all controlled under the same export control regime but are covered by a large number of international arrangements (including the Wassenaar Arrangement, the Nuclear Suppliers Group and the Missile Technology Control Regime) and even some national regimes (such as the United States Munitions List).[113] Some items are not covered at all. As discussed above, coordinating this quantity of data and identifying meaningful correlations would require a sophisticated data management system. Analysis of exports could be usefully supplemented by the Agency's own investigations into the nuclear black market, and possibly by international banking data which could yield evidence of the transfer of the funds used to procure equipment and materials.

Is the Agency entitled to conduct this kind of analysis for the purpose of identifying clandestine weaponization activities? There are two aspects to the analysis. First data must be collected; then they must be processed. Nothing in the IAEA's mandate explicitly prohibits it from collecting the required data; however, nothing in the mandate explicitly authorizes it to do so either.[114] A precedent is set, however, by some of the data collection activities the Agency undertakes as part of its current verification process. These activities, known collectively as information-driven safeguards, include the collection of unrestricted scientific papers, the acquisition of commercially available satellite imagery and investigations into the nuclear black market, and are likewise neither explicitly authorized nor prohibited by the Agency's mandate.[115] As far as the present authors know, however, no NPT state party has objected to this practice.

Of course, the possibility of the IAEA coming across evidence of weaponization activities when conducting routine verification should not be discounted. For example, the Agency's discovery that Iran had been irradiating bismuth-209 in a reactor led to its investigations into Iran's experiments involving polonium-210 and beryllium (see above). A future Agency investigation into the diversion of material from a safeguarded facility could likewise lead to evidence of a weaponization programme. It is unlikely, although not impossible, that the evidence acquired by the Agency in this way would be strong enough for it to initiate special inspections.

The following section considers how the IAEA could use these leads to produce more concrete evidence.

Further data collection

Once the Agency has a lead, it could use environmental or remote monitoring techniques to gather more evidence. It could employ wide-area environmental monitoring to look for some of the materials identified in table 3. Hyperspectral satellite imagery or airborne air sampling could also be employed to analyse the effluent of an industrial facility.[116] The same kind of imagery could also be used to detect these materials indirectly by looking for plant stress in nearby flora. The detection of materials would probably be most effective when dealing with an inexperienced proliferator who had not yet acquired experience in filtering the effluent from industrial facilities. High-resolution satellite imagery (either commercially available or provided by NTM) could be used to examine the external features of suspect facilities.

It is important to recognize the limitations of these remote monitoring technologies. They can be used to show the existence of activity in places where there should be none. Examples of this might include the transport of large numbers of people to a remote facility or unusually high levels of security around an industrial complex. However, while remote monitoring can give a bird's eye view of what is going on at ground level, it cannot be a substitute for direct human observation. It would be harder to use these techniques to distinguish between a facility used in a weaponization programme and one used for a legitimate purpose.

That is not to say, however, that there are no circumstances in which that would be possible. A good example of one such case is the use of consumables such as electricity. All industrial facilities use large amounts of electricity; it would therefore be practically impossible to identify a facility used in a weaponization programme on the basis of electricity usage. However, a weaponization facility disguised as an agricultural facility, say, could be uncovered if a high-voltage, high-power electricity supply were discovered. In any event, using these kinds of verification techniques it might be possible to gather sufficient evidence to invoke inspections.

Wide-area environmental monitoring is explicitly permitted where an additional protocol is in force. Under Article 9 of INFCIRC/540, the Agency may conduct wide-area environmental monitoring for 'the purpose of assisting the Agency to draw conclusions about the absence of undeclared nuclear material or nuclear activities over a wide area'.[117] The term 'nuclear activities' is not defined but must have a meaning different from the term 'nuclear material'. Nuclear activities may, therefore, include weaponization activities. Ultimately, the Board of Governors is responsible for establishing the procedural arrangements for the use of this verification technique (and presumably such procedural arrangements would specify in what circumstances it could be used). Where no additional protocol is in force the Agency does not have the authority to conduct wide-area environmental monitoring (which is precisely why this technique is included in INFCIRC/540).[118]

Airborne sampling is a measure technically similar to wide-area environmental monitoring. While it is not in use at the moment, it could possibly be used for the detection of weaponization R&D.

Inspections

Inspections have the potential to provide the most convincing evidence of a clandestine weaponization programme. The human ability to draw accurate conclusions from observable facts is arguably the sharpest instrument in the verification toolbox. The principal challenge is that a genuine proliferator is almost certain to be highly uncooperative. In the first place the proliferator might well refuse the requested access. In this case the problem becomes one of enforcement rather than verification. However, in the event of a proliferator being forced to comply with demands for inspections, or if it believes that weaponization activities can be concealed from inspectors, access may be granted. Either way, inspections must be robust enough to deal with a state that is intent on disguising the true purpose of the facilities being inspected. For this reason, the experience gained from conducting mock inspections to test the verifiability of a future nuclear disarmament agreement (where the host in generally assumed to be cooperative) is of limited relevance.[119]

This paper will not discuss in any depth how such inspections should be conducted. However, the following general observations should be made.

1. It would almost certainly be necessary to use inspectors who have detailed knowledge of weaponization. When equipment is carefully disguised, it generally requires an expert to be able to identify its true purpose.
2. The identification of the materials being used in a facility would be an important supplementary tool. Materials could be identified either by non-destructive assay techniques performed in situ or by taking environmental samples for subsequent analysis.
3. In practice, a series of inspections at different sites would probably be required. This has potential implications for the ease with which an inspection regime could be enforced. Specifically, it would be important for each new request for access to be facilitated rapidly, before evidence can be removed or other deception techniques employed.[120]

Open source indicators

In the previous section a strategy for detecting weaponization activities was discussed. This strategy is based around the use of 'conventional' verification techniques—inspections, remote monitoring and the collation and analysis of export data, for example. Conventional verification techniques will probably be central to any attempt at verifying military R&D because they have the potential to provide the strongest evidence possible of weaponization activities. In this section, we focus on the use of a more unconventional type of indicator—open source data. The use of open source data is discussed at length because it is very different from the use of more conventional verification techniques. Specifically, it might be possible to use open source data to identify trends (such as changes in the structure of the scientific community) which it is harder to pick up using conventional sources. On the other hand, open source data would probably be much less effective at identifying concrete evidence of activities that are clear indicators of weaponization (such as hydrodynamic testing). Open source indicators should, therefore, be viewed as a supplement to, not a replacement for, conventional sources.

The rationale behind looking for indicators in the open source scientific literature is as follows. Although the basic physics behind nuclear weapons is well known, there are still some formidable challenges—particularly engineering ones—confronting states that wish to develop them. The Manhattan Project is a case in point. It took the huge and stellar cast of scientists that the United States assembled at the Los Alamos weapons laboratory over two years to develop the first bomb (by the end of the war there were over 4,000 scientists based at Los Alamos, including about 20 past or future Nobel Prize winners).[121] Although the designs of the Fat Man and Little Boy bombs are known schematically, many of the details still remain classified. Any future proliferator must, at the very least, replicate some of the research performed at Los Alamos—and it must go even further if it is to develop a weapon small enough to be delivered by missile. The scale of this task should not be underestimated. It can only be accomplished in reasonable time by a state with a large base of suitably trained scientists. Open source literature is therefore useful because it can potentially yield information about changes in the structure and research agenda of the scientific community—the type of changes that are associated with a weapons programme.

Open source scientific literature has long been used to provide information about states' nuclear ambitions. In 1942, for example, Soviet physicist Georgii Flerov deduced the existence of a US nuclear weapons programme.[122] He was sitting in an abandoned library close to the front line at Voronezh, flipping through the most recent American physics journals, when he realized that they contained no articles on fission. This signalled to him that leading US scientists were engaged in a clandestine weapons programme. Today, as part of its verification efforts, the Agency runs an extensive programme of information-driven safeguards. These safeguards involve the analysis of open source data. The IAEA, for example, monitors the scientific literature using its own in-house database, INIS (the International Nuclear Information System),[123] Using INIS, the Agency was able to detect undeclared nuclear materials and activities in Egypt.[124]

One drawback of INIS, and other similar databases, is that they rely on information voluntarily submitted by member states. To circumvent this problem the IAEA is currently sponsoring the development of technology which can be used to collect and analyse information from the Internet. To increase the amount of information available to analysts, deep Web miners (which can search the 'hidden' Web) and translation software are being developed. To help the processing of information, the Agency has fostered the development of software which can analyse text.

Currently, information-driven safeguards are principally employed by the IAEA to detect clandestine fuel cycle activities. In this section, the use of open source scientific literature to search for evidence of weaponization is examined. Clearly, there are strong similarities between these two problems, and the Agency's extensive experience of information-driven safeguards gives it a strong base on which to build.

Over the past 10 years electronic journal publishing has become the norm. The abstracts of almost every published paper are available online. Databases to index and search that body of literature have also been developed. One such database, ISI Web of Knowledge[125] (generally regarded as the market leader), includes about 1,250 journals in fields that are broadly relevant to weaponization. The full text of papers published in almost every one of these journals is freely available on-line to subscribers or can be purchased electronically. These developments now provide any interested party with unprecedented access to the scientific activities of all countries, potential proliferators included.

In this paper, three strategies for using the open source literature are outlined and further questions for research are identified. These strategies are presented here for illustrative purposes only, but are nevertheless suitable bases for further study.

1. The trends approach

In this approach the literature is used to monitor the way a state's technical capabilities evolve over time. Specifically, the number of papers published in fields broadly relevant to weaponization is tracked. Attendance at conferences and workshops could be taken into account as lists of participants are often published.[126] This approach is promising because any potential proliferator must assemble a suitable scientific base. It would most probably send students abroad for training or try to encourage domestic graduate-level science programmes. As research students, these scientists would be unlikely to work on weaponization directly or even be aware of the existence of a nuclear weapons programme. In order to maintain secrecy while fostering the relevant skills, the state concerned would most probably fund them to work on closely related areas. During this period it is likely that the scientists concerned would publish regularly. Once they had completed their training, however, and were employed on a weapons programme it seems likely that they would be permitted to publish much less often, if at all.[127] This behaviour would be reflected in the data by a simultaneous upturn in the number of publications across a range of relevant fields, followed by a significant downturn. With experience, it might be possible to use the data to produce a rough estimate of how long a weaponization programme might take. The approach could be improved by tracking individuals—although there are clearly ethical problems with doing this.

The biggest challenge facing this method is interpreting the data. At the very least it would be necessary to filter the data to cut out noise, and then process it to separate meaningful trends from a general growth in scientific publishing. The larger the scientific community, or the smaller the fraction of a state's scientists engaged in weapons research, the harder this task would become.

2. The content-driven approach

It is not impossible that scientists engaged on a weapons project would be allowed to publish. Any publications would undoubtedly be carefully vetted and much research would be held back but even so it is possible that incriminating information might end up in the public domain. In the 'content-driven' approach, papers that are directly relevant to weaponization are sought out. There is a spectrum of possible strategies for doing this. At one extreme a list of keywords could be developed with 'hits' processed according to a strict protocol. Such a procedure could, in theory, be fully automated. At the other extreme, skilled users with experience of weaponization could be given free rein. The point about this approach is not that large returns of data are expected; rather the discovery of just one paper directly relevant to weaponization is a concern.

3. The institutional approach

The manufacture of a nuclear weapon is a multidisciplinary exercise. Even a single step, such as the development of explosive lenses, requires a range of experts based at the same facility working together—theoreticians with knowledge of shock waves and hydrodynamics, computer simulation specialists, high-explosive experts and experimentalists with expertise in high-speed measurements. Metallurgists and high-speed electronics experts might also be involved. The author affiliation data attached to most open source papers could be used to identify institutions with enough interdisciplinary expertise to undertake weaponization research.

This approach would only be successful if weaponization research were based in an institution that had civilian scientists employed in the same fields as those engaged on weapons research. Fortunately, a proliferator might well choose to base weapons research at such a facility in the belief that it would provide cover for the weaponization research, as well as relevant expertise.

This discussion raises two more general questions about the use of open source data. First, what is the relevant body of literature? Should searches be restricted to basic physics journals or broadened to include the whole of engineering and the physical sciences? Second, what search engines or databases should be used? It would, for instance, be interesting to compare the ISI Web of Knowledge[128] (the standard database of refereed publications), the Los Alamos pre-print server[129] (an un-refereed archive of papers submitted prior to publication) and Google Scholar.[130]

The implications of verifying military research and development

The implications for safeguards methodology

Searches for weaponization programmes would not only expand the range of activities undertaken by the IAEA; they would also require important changes to three different aspects of methodology—the role of judgement; the standard of proof; and the need to determine intent.

Accounting for the material in declared facilities, historically the Agency's core function, is sometimes termed a technical decision. Has any nuclear material been diverted from a safeguarded facility? There are only two possible answers—yes or no. Such an approach has obvious advantages. In answering this question the Agency can take a highly mechanistic approach in which individual judgement plays very little part. This is advantageous since it makes the safeguards system objective. Indeed, objectivity, impartiality and non-discrimination are important leitmotifs when the Agency is assessing its own system.

Nowadays, however, the IAEA is tasked with the additional function of verifying the completeness, as well as the correctness, of states' declarations. This determination cannot be made in a purely mechanistic way—judgement and inference must play a significant role.[131] Verifying the absence of weaponization activities will likewise require a large degree of judgement, probably more so than for fuel cycle activities. Needless to say, this is unlikely to be without political ramifications. The more the raw data must be processed before conclusions can be drawn, the more sceptical states may become about the Agency's conclusions.

A related issue is the standard of proof the Agency requires before it is willing to declare a state in breach of its safeguards agreement. As John Carlson puts it, 'conclusions about the absence of something—undeclared activities—can never be as definitive as conclusions based on quantitative methods applied to a finite problem—the verification of a declared inventory'.[132] Given the nature of the verification of weaponization activities, it is unlikely that the Agency would often be in a position to prove the existence of a weaponization programme beyond any doubt. In practice, the data produced by weaponization verification would be most useful if a lower standard of proof were employed. Indeed, Article 19 of INFCIRC/153, which states that the IAEA may declare a state in non-compliance if it is unable to verify that there has been no diversion to nuclear weapons, would seem to support the notion of lower standards of proof.

Finally, verifying military research and development might require the Agency to determine the intention of states. This, in turn, would require the Agency to properly revisit the general purpose criteria created by the drafters of the NPT to define manufacture. Article III of the NPT requires states to place safeguards on all nuclear materials. A state is in breach of its safeguards agreement, therefore, if its declaration is found to be either incomplete or incorrect, regardless of whether its intentions are peaceful or whether the breach was unintentional. In contrast, as the purpose criteria make clear, nuclear activities are illegal only if their purpose is military. Some activities (such as hydrodynamic tests) have no other purpose. Others (such as the expansion of a science base) often have a solely peaceful purpose. Ultimately weaponization searches may require the Agency to determine why a state is carrying out certain activities—something it has been very reluctant to do in the past.

Does the Agency's mandate need to be changed?

Having discussed the IAEA's current mandate and outlined what powers it would need in order to search for weaponization activities, there is one final question that has to be addressed: does the Agency's current mandate need to be changed in order for it to be able to implement weaponization searches? The discussion above seems to indicate that there is a substantial 'grey area' in the existing mandate. In the absence of the authority of an additional protocol, it is unclear whether the Agency has the authority to inspect weaponization activities which do not involve nuclear materials. If a suspect state does have an additional protocol in force then the Agency's inspection rights are somewhat enhanced.

There is a need to clarify this grey area, especially since some weaponization activities, such as hydrodynamic tests, fall within it. If, ultimately, the Agency's access rights are found to be limited only to those activities involving nuclear material, then its ability to find clandestine weaponization activities would be reduced.

On the face of it, some issues could be resolved through reinterpretation of the underlying legal instruments rather than going through a complicated revision and amendment process.

Ironically, there is even ambiguity over which organ of the IAEA is competent to clarify the Agency's mandate. According to the Statute, the relevant body is the General Conference which may 'discuss any questions or any matters . . . relating to the powers and functions of any organs provided for in the Statute, and may make recommendations . . . to the Board of Governors'.[133] However, the Board of Governors, which implements Agency policy, would not be bound by that decision unless it referred the question to the General Conference in the first place.[134]

Historically, the most significant clarification of the IAEA's mandate came at the start of Programme 93+2 when, before asking for any new powers, the Agency investigated whether it could use its existing authority more fully.[135] This investigation was conducted by the Board of Governors, not the General Conference. In practical terms, it is likely that any substantial rethink of the Agency's role in verifying military R&D would result from a general consensus over the need for change—much like the consensus built up following the discovery of Iraq's nuclear programme. In this case, the Board of Governors and General Conference would probably be in broad agreement and so the question of competency may become moot.

The authority to verify military research and development might be gained from a UN Security Council resolution. The use of a Security Council resolution to facilitate IAEA investigations into weaponization activities in Iraq was discussed above. Here a more general resolution, which requires all states to cooperate with Agency investigations into weaponization activities, is envisaged. Although it would probably be easier to pass such a resolution than to amend the Agency's mandate, it would also be extremely controversial because many states object to the Security Council acting as a 'world legislature'.[136] Indeed, the Security Council has recently passed two resolutions of a general nature, 1373 of 28 September 2001[137] and 1540 of 28 April 2004[138] and, although the former was relatively uncontroversial, the latter sparked a good deal of controversy.

The conditions for the use of special inspections are another important aspect of the IAEA's mandate. For special inspections to be an effective tool in searching for weaponization activities, the Agency would have to be more willing to request them than it has been in the past. Coupled to this, greater efforts would have to be made to ensure compliance with demands for access.[139] Only twice in the past have special inspections been instigated—in Romania and North Korea. In the former case they were conducted at the request of the state concerned to verify certain activities of the former regime.[140] Such eagerness to comply with special inspection provisions is not likely to materialize if the subject of inspections is a non-compliant state. Beyond that instance, the North Korean case clearly demonstrates that formal authority for special inspections does not necessarily translate into access on the ground. The Agency requested special inspections in North Korea in 1993.[141] This request was subsequently supported by the Board of Governors and then the Security Council in Resolution 825 of 11 May 1993.[142] To date this request has not been granted.

Ultimately, enforcement is the responsibility of the UN Security Council, not the IAEA. The latter's powers to deal with non-compliance are fairly limited.[143] Under its Statute the Agency is required to report non-compliant behaviour to the Security Council,[144] which does have coercive powers. If special inspections are to be used as a tool in the verification of military research and development, the Security Council must ensure that, once requested, special inspections actually happen.

Weaponization inspections and the proliferation dilemma

There are two proliferation-related problems the IAEA must solve if it is to verify military research and development on a regular basis. First, it would need a detailed knowledge of weaponization in order to design and carry out some parts of the verification process; however, Article I of the NPT (as well as quite obvious national security concerns) would prevent NWS from simply giving the Agency the required information. Related to that, there is the danger that inspectors would learn about the processes of weaponization by carrying out inspections.

The fact that the Agency does not have access to classified information may be less of a problem than it first appears, especially during the early stages of the verification process. As this paper has shown, much relevant information is already in the public domain. That is not to say, however, that weaponization searches could not be improved by employing classified information. Using environmental monitoring to find evidence for hydrodynamic tests of a plutonium device, for example, would require knowledge of the chemical composition of the relevant simulant. A detailed understanding of weaponization may also be required for analysing open source data. Indeed, there may well be other indicators of weaponization which are not discussed in this paper because they are classified and their existence is therefore unknown to the present authors. It is at the final stages of the verification process, however, that this problem becomes most acute. Given that a state intent on manufacturing a nuclear weapon would almost certainly attempt to disguise the true nature of its activities, first-hand knowledge of weaponization would probably be needed to design and then implement a successful inspection regime.

Historically, the Agency's solution to both problems has been to second weaponization specialists from NWS to its inspectorate. It would, however, probably be problematic to use NWS specialists on a more routine basis. In the past, NWS have sometimes had less than friendly relations with the states that their seconded inspectors are supposed to visit. Because it can be argued that the verification process is helped by the recipient state viewing the inspector as neutral (as the state will then be keener to cooperate), the deployment of

NWS specialists can sometimes undermine the Agency's verification process. For this reason NWS specialists should be used as sparingly as possible. There will probably be some occasions on which there is no alternative. It may well prove necessary, for example, for inspections of suspect facilities to be carried out by NWS specialists with the appropriate national security clearance. However, at the early stages of the verification process, it seems both desirable and plausible to use the Agency's own inspectorate as much as possible. In addition, there may be technological solutions—such as the concept of the information barrier—which might permit some fairly sensitive verification activities to be undertaken by the Agency's own inspectors.

The concept of the information barrier originated with the Trilateral Initiative, which gives the Agency responsibility for verifying weapons-origin nuclear fuel from the United States and Russia once it has been reintroduced into the civilian nuclear fuel cycle.[145] Under the Trilateral Initiative, Agency inspectors will not have direct access to nuclear weapons or their components. Rather, they will use monitoring technology with a 'filtered output' so that proliferation-sensitive information is not divulged. A similar concept could be applied to certain types of weaponization investigations, such as environmental monitoring to detect the simulant used in hydrodynamic tests for a plutonium device. In this case the monitoring device would merely indicate whether it had detected the simulant without revealing any details about its composition.

Conclusions

The most difficult challenge facing a potential proliferator is the acquisition of fissile material. For this reason, the verification of fuel cycle activities is always going to be at the heart of the nuclear non-proliferation regime. The verification of military research and development may, however, be a useful supplement—especially because it is possible for a state to obtain fissile material without first acquiring enrichment or reprocessing technology (by purchase or theft, for example).

Weaponization leaves enough of a footprint that by undertaking concerted and systematic searches the IAEA would have a reasonable chance of uncovering the existence of a clandestine weaponization programme before its completion. The best evidence for this comes from Iran. It is not yet known whether Iran is trying to develop nuclear weapons. However, even without conducting systematic searches for them, the Agency has uncovered various indicators which might point to the existence of a nuclear weapons programme. It is therefore reasonable to suggest that if the Agency were to undertake such searches it would have a reasonable chance of success. The prospects for success could be enhanced by using a variety of independent indicators and by making use of the experience it has already acquired of verifying military R&D in Iran, Iraq, Libya and South Africa. Nonetheless it is important to be realistic. Although it seems possible to detect a clandestine weaponization programme, success is far from guaranteed. In contrast to the detection of clandestine fuel cycle activities, it seems unlikely that the Agency could ever be a position to provide credible assurances of the *absence* of weaponization efforts in a state.

In addition to detecting a clandestine weaponization programme, IAEA investigations could have two other effects. First, they might act as a deterrent to states developing nuclear weapons. This deterrent effect stems partly from the risk of being caught, but might also result from the increased costs of hiding a weaponization programme. Second, if the Agency found evidence of weaponization activities, it could enhance its scrutiny of a state's fuel cycle activities. This would apply even if the Agency had no specific powers to investigate military research and development.

This paper has focused on the technical and legal aspects of verifying military research and development. In closing, it might be appropriate to say a few words about politics. The technical feasibility of searching for weaponization is only one part of the broader debate about its desirability. That debate encompasses issues of cost and national sovereignty. It also includes the question of what effect these searches would have on the Agency's relations with member states. As noted above, for example, there are some significant differences between verifying military R&D and the Agency's other activities: interpreting the data would require more use of inference, the evidence produced would probably be less conclusive and it might prove necessary to try to determine the intention of states.

There are two distinct forums for the debate about weaponization—within the IAEA; and between national governments. Acting strictly within its mandate, the Agency could, if it chose, use its existing powers to investigate weaponization more fully. It would, for example, be relatively uncontroversial for the Agency to increase its use of information sources which could provide evidence of both fuel cycle activities and weaponization activities. Other steps, such as using wide-area environmental monitoring in states with an additional protocol to detect evidence of hydrodynamic tests, would be much more contentious.

In the current political climate, even a debate about increasing the Agency's authority in this direction seems unlikely. But political realities can change. The last major rethink of the Agency's role, Programme 93+2, which culminated with the adoption of the Model Additional Protocol in 1997, was a consequence of the Agency's failings in Iraq coming to light. The potential fallout from some future crisis—or even the current crisis over Iran—may precipitate a broader debate about weaponization. In the longer term, disarmament may once again become a live political issue. Weaponization inspections are likely to play an important role in any future disarmament process. Indeed, it is interesting to note that much of the existing research into the verification of military R&D has been conducted in the context of disarmament studies.[146]

Endnotes

1 The term 'weaponization' is sometimes used to mean the manufacture of a deliverable nuclear weapon, as distinct from the process of manufacturing a prototype nuclear device. In this paper no such distinction is made; weaponization should be understood to include every part of the process of manufacturing a nuclear weapon or other nuclear explosive device, except for the acquisition of fissile material.

2 Andreas Persbo (with Ben Mayo and Matthew Peterson), 'An overview of the evolution, operation and status of nuclear safeguards', Comparative Case Study 2, VERIFOR (no date), www.verifor.org/case_studies/nuclear.html.

3 Mohamed ElBaradei, 'In search of security: Finding an alternative to nuclear deterrence', Remarks at the Center for International Security and Cooperation, Stanford University 4 November 2004, www.iaea.org/NewsCenter/Statements/2004/ebsp2004n012.html.

4 David Albright and Khidhir Hamza, 'Iraq's reconstitution of its nuclear weapons program', *Arms Control Today,* vol. 28, no. 7, October 1998, pp. 9–15.

5 An initiator is a device for injecting neutrons into the core of nuclear weapon to start a chain reaction at exactly the right moment.

6 Explosive lenses are the high-explosive charges used to compress the nuclear material in an implosion-type nuclear weapon thereby detonating it.

7 Albright and Hamza.

8 Interview with an Iraqi nuclear scientist.

9 UN Security Council, 'Note by the Secretary-General', UN document S/1997/779, 8 October 1997, www.iaea.org/worldatom/Programmes/ActionTeam/reports/s_1997_779.pdf, pp. 49–50.

10 Treaty on the Non-Proliferation of Nuclear Weapons, 1968, www.iaea.org/Publications/Documents/Infcircs/Others/infcirc140.pdf.

11 Treaty on the Non-Proliferation of Nuclear Weapons, 1968, Article III.

12 International Atomic Energy Agency, 'The structure and content of agreements between the Agency and states required in connection with the Treaty on the Non-Proliferation of Nuclear Weapons', INFCIRC/153, June 1972, www.iaea.org/Publications/Documents/Infcircs/Others/infl53.shtml.

13 Victor Bragin, John Carlson and Russell Leslie, 'Integrated safeguards: Status and trends', *Nonproliferation Review,* vol. 8, no. 2, 2001, pp. 102–110.

14 Suzanna van Moyland, 'The IAEA's Programme "93+2"', *Verification Matters,* no. 10, Verification Technology Information Centre (VERTIC), London, January 1997.

15 Treaty on the Non-Proliferation of Nuclear Weapons, 1968, Article III.1.

16 International Atomic Energy Agency, 2000 Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons, 'Final Document', NPT/CONF.2000/28, 2000, www.nti.org/db/china/engdocs/nptfd_00.pdf, p. 3.

17 International Atomic Energy Agency, 'Statute of the IAEA', 1956, www.iaea.org/About/statute_text.html.

18 International Atomic Energy Agency, 'Model protocol additional to the agreement(s) between state(s) and the International Atomic Energy Agency for the application of safeguards', INFCIRC/540 (Corrected), September 1997, www.iaea.org/Publications/Documents/Infcircs/1998/infcirc540corrected.pdf.

19 Jozef Goldblat, *Arms Control: A New Guide to Negotiations and Agreements,* 2nd edn, Sage Publications, London, 2002, p. 102.

20 Quoted in George Bunn and Roland M. Timerbaev, 'Nuclear verification under the NPT: What should it cover—how far may it go?', Programme for Promoting Nuclear Non-Proliferation Study 5, Mountbatten Centre for International Studies, University of Southampton, April 1994.

21 Where no additional protocol is in force, special inspections are the only type of inspection that can be used to gain access to undeclared activities. The complementary access provisions of an additional protocol are considered below.

22 See the discussion below about Agency activities in Iran.

23 INFCIRC/153, para. 73.

24 INFCIRC/153, para. 28. Emphasis in original.

25 These are experiments for determining the properties of an assembly of fissile material just below its criticality threshold, i.e. when almost enough material is present for a chain reaction to start spontaneously.

26 The pit is the spherical (or nearly spherical) mass of fissile material at the centre of an implosion-type nuclear weapon.

27 John Carlson and Russell Leslie, 'Special inspections revisited', Australian Safeguards and Non-Proliferation Office, July 2005, www.asno.dfat.gov.au/publications/inmm2005_special_inspections.pdf.

28 Quoted in Bunn and Timerbaev.

29 Mohamed ElBaradei, 'Nuclear non-proliferation and arms control: Are we making progress?', Remarks at the 2005 Carnegie International Non-Proliferation Conference, Washington DC, 7 November 2005, www.iaea.org/NewsCenter/Statements/2005/ebsp2005n017.html.

30 David Fischer, *History of the International Atomic Energy Agency,* International Atomic Energy Agency, Vienna, 1997, pp. 288–294.

31 INFCIRC/540 (corrected), Article 5. The term 'site' is defined in Article 18.

32 INFCIRC/540 (corrected), Article 18.

33 This provision is potentially significant because it is quite possible that nuclear material would not be present at a facility where a state was developing this kind of technology. Because of the scarcity of nuclear material, casting or milling technology would typically be tested on a simulant, such as natural or depleted uranium, which, because of the small quantities involved, may be exempted from safeguards under paragraph 37 of INFCIRC/153. Other simulants may be exempt from safeguards entirely.

34 See INFCIRC/540 (corrected), Articles 2.a.(i), 4.a.(ii) and 5.b.

35 Bunn and Timerbaev.

36 Leonard Weiss, 'The nuclear nonproliferation treaty: Strengths and gaps', in Henry Sokolski (ed.), *Fighting Proliferation: New Concerns for the Nineties,* Air University Press, Washington, DC, 1996 (chapter 2), available at www.fas.org/irp/threat/fp/b19ch2.htm.

37 *Lex specialis derogat generali.*

38 Contained in International Atomic Energy Agency, 'The text of the agreement between Iran and the Agency for the application of safeguards in connection with the Treaty on the Non-Proliferatio [*sic*] of Nuclear Weapons', INFCIRC/214, 13 December 1974, www.iaea.org/Publications/Documents/Infcircs/Others/infcirc214.pdf.

39 The Additional Protocol was applied voluntarily until February 2006.

40 Contained in International Atomic Energy Agency, 'The text of the agreement between Iraq and the Agency for the application of safeguards in connection with the Treaty on the Non-Proliferation of Nuclear Weapons', INFCIRC/172, 22 February 1973, www.iaea.org/Publications/Documents/Infcircs/Others/infcirc172.pdf.

41 Contained in International Atomic Energy Agency, 'The text of the agreement of 8 July 1980 between the Libyan Arab Jamahiriya and the Agency for the application of safeguards in connection with the Treaty on the Non-Proliferation of Nuclear Weapons', INFCIRC/282, [October 1980].

42 Provisionally applied pending entry into force.

43 Investigations were ongoing at time of the most recent safeguards statement (2004). See International Atomic Energy Agency, 'Safeguards statement for 2004' (undated), www.iaea.org/OurWork/SV/Safeguards/es2004.html, para. 4.

44 Contained in International Atomic Energy Agency, 'Agreement of 16 September 1991 between the Government of the Republic of South Africa and the International Atomic Energy Agency for the application of safeguards in connection with the Treaty on the Non-Proliferation of Nuclear Weapons', INFCIRC/394, [October 1991].

45 International Institute for Strategic Studies, 'Iran's strategic weapons programmes: A net assessment', *Strategic Dossier,* Routledge, London, 2005.

46 International Atomic Energy Agency, 'Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran', GOV/2006/15, 27 February 2006, www.iaea.org/Publications/Documents/Board/2006/gov2006-15.pdf. para. 20.

47 GOV/2006/15, para. 38.

48 GOV/2006/15, para. 38.

49 International Atomic Energy Agency, 'Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran', GOV/2004/83, 15 November 2004, www.iaea.org/Publications/Documents/Board/2004/gov2004-83.pdf, paras 79–84.

50 GOV/2006/15, para. 52.

51 GOV/2006/15, para. 33.

52 International Atomic Energy Agency, 'Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran', GOV/2003/75, 10 November 2003, www.iaea.org/Publications/Documents/Board/2003/gov2003-75.pdf, annex 1, para. 36.

53 David Albright and Corey Hinderstein, 'Parchin: Possible nuclear weapons-related site in Iran', Institute for Science and International Security (ISIS), 13 September 2004, www.isis-online.org/publications/iran/parchin.html.

54 UN Security Council Resolution 687, 3 April 1991, www.un.org/Docs/scres/1991/scres91.htm.

55 UN document S/1997/779, p. 92.

56 For an overview of Iraq's nuclear weapons programme see International Atomic Energy Agency, 'Fact sheet: Iraq's nuclear weapon programme', 27 December 2002, www.iaea.org/worldatom/Programmes/ActionTeam/nwp2.html.

57 UN document S/1997/779, p. 69.

58 UN document S/1997/779, p. 71.

59 Jacques Baute, 'Timeline Iraq: Challenges and lessons learned from nuclear inspections', *IAEA Bulletin*, vol. 46, no. 1, June 2004, pp. 64–68.

60 UN document S/1997/779, p. 62.

61 UN Security Council, 'Note by the Secretary-General', UN document S/1995/287, 11 April 1995, www.iaea.org/OurWork/SV/Invo/reports/s_1995_287.pdf, para. 12.

62 Khidhir Hamza, 'Inside Saddam's secret nuclear program', *Bulletin of the Atomic Scientists,* vol. 54, no. 05, 1998, pp. 26–33.

63 UN document S/1997/779, p. 92.

64 UN document S/1997/779, p. 70.

65 Stockholm International Peace Research Institute, *SIPRI Yearbook 1999: Armaments, Disarmament and International Security,* Oxford University Press, Oxford, 1999, pp. 586–592.

66 UN document S/1997/779, paras 73–83. These questions were highlighted in 1997 and were still unresolved at the time when the Agency left Iraq the following year.

67 UN Security Council, 'Letter dated 7 April 1999 from the Secretary-General addressed to the President of the Security Council', UN document S/1999/393, 7 April 1999, www.iaea.org/OurWork/SV/Invo/reports/s_1999_393.pdf, p. 7.

68 Stockholm International Peace Research Institute, *SIPRI Yearbook 2003: Armaments, Disarmament and International Security*, Oxford University Press, Oxford, 2003, pp. 592–596.

69 Stockholm International Peace Research Institute, *SIPRI Yearbook 2005: Armaments, Disarmament and International Security,* Oxford University Press, Oxford, 2005, pp. 566–576.

70 Baute.

71 See www.iaea.org/OurWork/SV/Invo/about.html.

72 Adolf von Baeckmann, Gary Dillon and Demetrius Perricos, 'Nuclear verification in South Africa', *IAEA Bulletin*, vol. 37, no. 1, 1995, pp. 42–58; all the information in this report about the South African nuclear programme is taken from this source. It is interesting to note how little information about Agency investigations in South Africa has been released compared to that available about Iran, Iraq and Libya.

73 International Atomic Energy Agency, 'Implementation of the NPT Safeguards Agreement of the Socialist People's Libyan Arab Jamahiriya', GOV/2004/12, 20 February 2004, www.iaea.org/Publications/Documents/Board/2004/gov2004-12.pdf, paras 2–3.

74 Jack Boureston and Yana Feldman, 'Verifying Libya's nuclear disarmament', *Verification Yearbook 2004,* Verification Research, Information and Training Centre (VERTIC), London, 2004 (chapter 5), www.vertic.org/assets/YB04/Boureston-Feldman%209.pdf.

75 GOV/2004/12, paras 30–31; and SIPRI 2005, pp. 553–554.

76 Boureston and Feldman.

77 GOV/2004/12, para. 32.

78 International Atomic Energy Agency, 'Implementation of the NPT Safeguards Agreement of the Socialist People's Libyan Arab Jamahiriya', GOV/2004/33, 28 May 2004, www.fas.org/nuke/guide/libya/iaea0504.pdf, annexes 3–4.

79 International Atomic Energy Agency, 'Implementation of the NPT Safeguards Agreement of the Socialist People's Libyan Arab Jamahiriya', GOV/2004/59, 30 August 2004, www.iaea.org/Publications/Documents/Board/2004/gov2004-59.pdf, paras 32–34.

80 David Albright, 'South Africa and the affordable bomb', *Bulletin of the Atomic Scientists,* vol. 50, no. 4, 1994, pp. 37–47.

81 International Atomic Energy Agency, 'The safeguards implementation report for 2004', GOV/2005/32, 13 May 2005.

82 International Atomic Energy Agency, 'IAEA Illicit Trafficking Database (ITDB)', 31 December 2004, www.iaea.org/NewsCenter/Features/RadSources/PDF/itdb_31122004.pdf.

83 Jaime Vidaurre-Henry, William Lichliter and Thomas Killeen, 'Challenging curriculum: Training the IAEA international safeguards inspectorate', *IAEA Bulletin*, vol. 43, no. 1, 2001, pp. 41–45.

84 Oliver Meier, 'Fulfilling the NPT: Strengthened nuclear safeguards', VERTIC Briefing Paper 00/2, Verification Research, Information and Training Centre (VERTIC), London, April 2000.

85 United Kingdom, 'Verification of nuclear disarmament: Final report on studies into the verification of nuclear warheads and their components', Working paper submitted to the 2005 Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons, NPT/CONF.2005/WP.1, 18 April 2005, www.fco.gov.uk/Files/kfile/WP01%20Verification%20-%20UK,0.pdf.

86 The only indicators discussed in this paper are those related to a fission programme. The aim of verifying military R&D is to detect a weaponization programme *before* a state has manufactured a nuclear weapon. It is widely believed that it is necessary to test a simple fission device before serious work on a boosted fission or fusion programme can begin. Such a test would almost certainly be detected. At the very least, even if a state decided not to test, it would be highly unlikely to start a determined boosted fission or fusion programme until it had succeeded in manufacturing its first fission device. The indicators of a boosted fission or fusion programme (the production of lithium-6, tritium and deuterium, for example) would, therefore, only be visible after a state had proliferated.

87 Personal communication with Peter Zimmerman, chair of the committee which drew up the Militarily Critical Technologies List for the US government, the most comprehensive publicly available list of equipment used in the development of nuclear weapons.

88 Quoted in Bunn and Timerbaev.

89 Eric Arnett, 'Norms and nuclear proliferation: Sweden's lessons for assessing Iran', *Nonproliferation Review*, vol. 5, no. 2, 1998, pp. 32–43.

90 United Kingdom, 'Verification of nuclear disarmament', 2005.

91 US Department of Defense, 'Nuclear Weapons Technology', section V of *The Militarily Critical Technologies List Part II: Weapons of Mass Destruction Technologies,* Office of the Under Secretary of Defense Research and Engineering, Washington, DC, February 1998, www.fas.org/irp/threat/mctl98-2/index.html; Los Alamos National Laboratory, 'Nuclear weapon proliferation indicators and observables', LA-12430-MS, December 1992, www.fas.org/sgp/othergov/doe/lanl/la-12430-ms.pdf; and US Office of Technology Assessment, 'Technical aspects of nuclear proliferation', chapter 4 of *Technologies Underlying Weapons of Mass Destruction,* OTA-BP-ISC-115, US Government Printing Office, Washington, DC, 1993, www.wws.princeton.edu/ota/disk1/1993/9344/934406.PDF.

92 The equipment listed in the table must meet certain minimum specifications for it to be of use in weaponization. Numerically-controlled measuring devices, for example, must be both accurate and precise enough to be useful for fabricating the pit of a nuclear weapon.

93 International Atomic Energy Agency, *The Evolution of IAEA Safeguards,* International Nuclear Verification Series no. 2, International Atomic Energy Agency, Vienna, 1998, pp. 56–58.

94 Not all weapon designs require an initiator. In particular it is possible to build a gun-type weapon without one—as South Africa demonstrated. On balance, however, it is highly likely that a proliferator would attempt to develop a weapon with an initiator, especially if an implosion weapon were being sought.

95 David Albright and Kevin O'Neill, 'Iraq's efforts to acquire information about nuclear weapons and nuclear-related technologies from the United States', Institute for Science and International Security (ISIS), 12 November 1999, http://isis-online.org/publications/iraq/infogather.html. EMIS is a form of enrichment technology which employs electric and magnetic fields.

96 US Department of Defense, 'Nuclear Weapons Technology'.

97 Richard Rhodes, *The Making of the Atomic Bomb,* Simon & Schuster, New York, 1988, pp. 573–578.

98 Keith O'Nions, Robin Pitman, and Clive Marsh, 'Science of nuclear warheads', *Nature,* vol. 415, no. 6874, 2002, pp. 853–857.

99 US Office of Technology Assessment, 'Technical aspects of nuclear proliferation'.

100 O'Nions, Pitman and Marsh.

101 O'Nions, Pitman and Marsh.

102 Hydrodynamic tests that involve nuclear material in subcritical amounts are more properly known as hydronuclear tests.

103 O'Nions, Pitman and Marsh.

104 Personal communication with Peter Zimmerman. It would be more difficult and much more expensive to conduct full-scale hydrodynamic tests underground than on the surface.

105 Los Alamos National Laboratory, 'Nuclear weapon proliferation indicators and observables'.

106 Los Alamos National Laboratory, 'Nuclear weapon proliferation indicators and observables'.

107 In addition to those listed in table 3, two other methods have been used to monitor hydrodynamic tests—the RaLa method and neutron

photography. The RaLa method involves filling the centre of the pit with a highly radioactive isotope of lanthanum. As discussed below in this section, environmental monitoring could be used to detect lanthanum or, more likely, its decay products. Neutron photography is another possibility but, because of its complexity, it is considered to be a less likely choice than X-ray photography. On balance it seems unlikely that either of these methods would be chosen.

108 Los Alamos National Laboratory, 'Nuclear weapon proliferation indicators and observables'.

109 Michael A. Levi and Michael E. O'Hanlon, *The Future of Arms Control,* Washington, DC, Brookings Institution Press, 2005, p. 63.

110 US Office of Technology Assessment, *Environmental Monitoring for Nuclear Safeguards,* OTA-BP-ISS-168, US Government Printing Office, 1995, www.wws.princeton.edu/ota/disk1/1995/9518/9518.PDF.

111 Some of the early British hydrodynamic test sites were covered by massive slabs of reinforced concrete. This design would significantly curtail the spread of material from a hydrodynamic test.

112 As stated above, Article VIII.A of the Agency's Statute permits member states to give it useful information.

113 US Department of Defense, 'Nuclear Weapons Technology'.

114 Article 2 of INFCIRC/540 does authorize the Agency to collect data on exports, but only for equipment that is used in the fuel cycle. Although some items that are useful for weaponization are also useful for the fuel cycle (such as equipment for fabricating nuclear fuel), the majority are not.

115 It has been argued that these techniques are permitted by paragraph 6 of INFCIRC/153, which states that 'the Agency shall take full account of technological developments in the field of safeguards'. However, this argument is somewhat unconvincing because Article 6 refers specifically to processes for 'safeguarding effectively the flow of nuclear material' within facilities.

116 United Kingdom, 'Verification of nuclear disarmament', 2005.

117 INFCIRC/540 (corrected), Article 9.

118 International Atomic Energy Agency, 'Strengthening the effectiveness and improving the efficiency of the safeguards system', GOV/2784, 21 February 1995, para. 54.

119 United Kingdom, 'Verification of nuclear disarmament: Second interim report on studies into the verification of nuclear warheads and their components', Working paper submitted to the Preparatory Committee for the 2005 Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons, NPT/CONF.2005/PC.III/WP.3, 8 April 2004, www.reachingcriticalwill.org/legal/npt/prepcom04/papers/UKwp3.pdf.

120 Israel employed several quite successful deception techniques at its Dimona facility in the Negev Desert. For instance, it built up fake walls and even a fake control room to convince outsiders that the facility was used for peaceful purposes. It called the facility a manganese plant and, occasionally, a textile plant. However, 'hundreds of French engineers and technicians filled Beersheba, the biggest town in the Negev [and the] concentration of Frenchmen was impossible to hide from ground observers'. See Warner D. Farr (Lieutenant-Commander), 'The Third Temple's Holy of Holies: Israel's nuclear weapons', Counterproliferation Papers, Future Warfare Series No. 2, USAF Counterproliferation Center, Alabama, 1999.

121 Rhodes, p. 549.

122 David Holloway, *Stalin and the Bomb: The Soviet Union and Atomic Energy, 1939–1956,* Yale University Press, New Haven, Conn., 1994, p. 78.

123 Taghrid Atieh and Robert Workman, 'INIS: The world's nuclear knowledge reservoir', *IAEA Bulletin,* vol. 47, no. 1, 2005, pp. 50–51.

124 Paul Kerr, 'IAEA: Egypt's reporting failures "matter of concern"', *Arms Control Today,* vol. 35, no. 2, 2005.

125 See www.isinet.com/.

126 This is very similar to some of the work that the Agency currently undertakes using link analysis software as part of its efforts to search for clandestine fuel cycle activities.

127 Los Alamos National Laboratory, 'Nuclear weapon proliferation indicators and observables'.

128 See www.isinet.com/.

129 See http://xxx.lanl.gov/.

130 See http://scholar.google.com/.

131 John Carlson, 'Safeguards in a broader policy perspective: Verifying treaty compliance', Australian Safeguards Non-proliferation Office, 2005, www.asno.dfat.gov.au/publications/2005_santa_fe_policy.pdf.

132 Carlson.

133 International Atomic Energy Agency, 'Statute of the IAEA', Article V-D.

134 International Atomic Energy Agency, 'Statute of the IAEA', Article V-F1.

135 van Moyland.

136 See, for instance, the discussion preceding the adoption of UN Security Council Resolution 1540, contained verbatim in UN Security Council, '4590th meeting', UN document S/PV.4950, 22 April 2004; UN Security Council, '4590th meeting', UN document S/PV.4950 (Resumption 1), 22 April 2004; UN Security Council, '4596th meeting', UN document S/PV.4956, 28 April 2004 (all available at www.un.org/depts/dhl/resguide/scact2004.htm).

137 Adopted after the 11 September 2001 attacks, this resolution requires states to take steps to combat terrorism.

138 This resolution requires states to take certain enumerated steps to combat the proliferation of nuclear, chemical and biological weapons.

139 Carlson and Leslie.

140 Carlson and Leslie.

141 Fischer.

142 UN Security Council Resolution 825, 11 May 1993, www.un.org/Docs/scres/1993/scres93.htm.

143 According to Article XII.7-C of the Agency's Statute, in the event of a state not rectifying non-compliant behaviour 'the Board may take one or both of the following measures: direct curtailment or suspension of assistance being provided by the Agency or by a member, and call for the return of materials and equipment made available to the recipient member or group of members. The Agency may also, in accordance with article XIX, suspend any non-complying member from the exercise of the privileges and rights of membership'.

144 International Atomic Energy Agency, 'Statute of the IAEA', Article XII.7-C.

145 International Atomic Energy Agency, 'IAEA verification of weapon-origin fissile material in the Russian Federation and the United States', Press release 2001/16 (no date), www.iaea.org/NewsCenter/PressReleases/2001/prn0119.shtml.

146 United Kingdom, 'Verification of nuclear disarmament', 2005; and Tom Milne and Henrietta Wilson, 'Verifying nuclear disarmament: A role for AWE Aldermaston', British Pugwash Group, London, 1999.