Verifying Warhead Dismantlement

Past, present, future

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VERIFICATIONMATTERS

VERTIC RESEARCH REPORTS
NUMBER 9 ● SEPTEMBER 2010

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Current funders

Canadian Ministry of Foreign Affairs, Carnegie Corporation of New York, Foundation for Environmental Law and Development, Joseph Rowntree Charitable Trust, Netherlands Ministry of Foreign Affairs, Norwegian Ministry of Foreign Affairs, Norwegian Radiological Protection Authority, Ploughshares Fund, Swedish Ministry of Foreign Affairs, UK Foreign & Commonwealth Office, World Resources Institute.

This report is funded by the Carnegie Corporation of New York under project title 'The UK-Norway Initiative: Report of the Independent Observer'.

Research contributions by Hugh Chalmers, Sonia Drobysz, Timothy Collins, William Eichler and Martin Groarke.

Special thanks to James M. Acton, Marius Bjørningstad, Glenn Kelly, Morten Bremer-Maerli, Kathleen McNamara, Jasper Pandza, Ole Reistad and Carl Robichaud. Thanks also to our reviewers, who travelled many miles to join us in London for two days in June 2010.

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Printed in the United Kingdom by XXXX

ISSN 1474-8045

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Abbreviations

ACDA	(US) Arms Control and Disarmament Agency (now part of the US State Dept)
AEC	(US) Atomic Energy Commission (defunct since 1974)
AWE	(UK) Atomic Weapons Establishment
CBMs	Confidence-building measures
CCTV	Closed-circuit television
CSA	Canned Sub Assembly
DoD	(US) Department of Defense
DOE	(US) Department of Energy
FFI	Norwegian Defence Research Establishment
HEU	Highly-enriched uranium
IAEA	International Atomic Energy Agency
IFE	Norwegian Institute of Energy Technology
IFS	Norwegian Institute of Defence Studies
NDA	Non-Destructive Assay
NWS	Nuclear-weapon state (under the NPT)
NNWS	Non-nuclear-weapon state (under the NPT)
NORSAR	Norwegian Seismic Array
NPT	Nuclear Non-Proliferation Treaty (opened for signature 1968)
NRPA	Norwegian Radiation Protection Authority
PMDA	Plutonium Management Disposition Agreement
PPCM	Portal Perimeter Continuous Monitoring
RD/FRD	Restricted Data/Formerly Restricted Data

RPIT	Random Particulate Identification Technique
SDR	(UK) Strategic Defence Review
SLCM	Sea-launched cruise missile
SORT	Strategic Offensive Reductions Treaty (signed 2002)
START	Strategic Arms Reduction Treaty (signed 1991)
TIEs	Tamper Indicating Enclosures
TLI	Treaty Limited Item
U to C/NSI	Unclassified to Confidential National Security Information
USSR	Union of Soviet Socialist Republics
VERTIC	Verification Research, Training and Information Centre

1. Preface

In July 1998, in the United Kingdom's Strategic Defence Review, George Robertson, the Secretary of State for Defence stated:

> "... The government wishes to see a safer world in which there is no place for nuclear weapons. Progress on arms control is therefore an important objective of foreign and defence policy ... The effectiveness of arms control agreements depends heavily on verification. The United Kingdom has developed particular expertise in the monitoring of fissile materials and nuclear tests. We plan to add to this by developing capabilities which could be used to verify reductions in nuclear weapons, drawing on the expertise of the Atomic Weapons Establishment at Aldermaston. This will begin with a study lasting some 18 months to identify the technology, skills and techniques required and what is available in this country."

Immediately, the UK Government turned these words into action. At the 2000 Nuclear Non-Proliferation Treaty (NPT) Review Conference, the UK presented the findings of that study and announced a research programme on verification aimed at developing the techniques required to address the issues associated with verifying the dismantlement of nuclear weapons.

At the 2005 NPT Review Conference, the UK submitted a working paper on the verification of nuclear disarmament. In that paper, the UK took the research a step further, offering collaborative work with a non-nuclear-weapon state (NNWS) to examine the dismantlement verification challenges of engagement between a NNWS and a nuclear-weapon state (NWS). This was an unprecedented and ambitious initiative, designed to improve confidence in the commitment of the UK as an NWS to the process of disarmament.

However, overall, the 2005 RevCon was widely perceived to be a failure. Unlike the recently concluded 2010 RevCon, no final outcome document or action plan was agreed. Among the reasons for that failure was a widely held view that the NWSs had gone cold on their nuclear disarmament obligations. The 'grand bargain' that is the foundation of the NPT came under great pressure. In particular, confidence was waning in the NWSs commitment to end the nuclear arms race and eventually to disarm.

It was in that context that, in May 2006, on my appointment to the role of Secretary of State for Defence, I assumed the awesome, but shared, responsibility for our country's nuclear deterrent. The challenge that Margaret

Beckett, as Foreign Secretary, and I faced was to help re-energise the international consensus that underpinned the NPT and to renew and refresh the treaty itself by strengthening each of its three pillars: non-proliferation, disarmament and peaceful uses of nuclear energy. Together, we set out a strategy of international leadership on these issues. We set out our vision, subsequently endorsed by President Obama, of a world free of nuclear weapons as a vital political goal in its own right, as ultimately the only means to be absolutely certain that nuclear weapons would never be used again. We acknowledged that to unite the international community against proliferation, the nuclear-weapons states needed to be seen to push forward on disarmament, and we reiterated the critical necessity of transparent verification to the process of eliminating nuclear weapons.

It was in the context of the post-2005 RevCon challenges, that in 2007, Norway joined the UK to progress a programme of work on the verification of dismantlement. As a result, the UK-Norway Initiative (UKNI) was born. The UKNI is a unique collaboration between a NWS and a NNWS; the first time that a NWS and a NNWS have carried out such joint work. As this report makes clear, the Initiative provided participants with a unique opportunity to appreciate the challenges faced by a NNWS and NWS in such a collaboration. Only with such an appreciation and a recognition of the need for trust and confidence-building can states parties to the NPT hope to move beyond their stovepipes and come together in their joint obligations under Article VI of the Treaty.

As important, and as unique, has been the involvement in this Initiative of VERTIC. The pedigree of VERTIC as an independent organisation in promoting effective verification in the implementation of international agreements has enhanced greatly the credibility and transparency of the work.

The work of the UKNI catalogued in this report is but the latest small step along a long road. The challenges of such collaboration having been identified, the UK and Norway must continue to work together to develop their joint work on the basis of what has been learned to date.

The context for the publication of this report and for that continuing challenge is significantly different from the context when the UKNI was born. The 2010 NPT Review Conference is widely regarded as a significant success, not least because a final document setting out recommendations for follow-on actions, among other things, was agreed by consensus. Despite a sense that the NPT regime is now back on track, there is little room for complacency. It is the implementation of the agreed non-proliferation and disarmament actions that will be the measure of success of the 2010 Review Conference. In the words of Ban Ki-moon, the UN Secretary General, in his address to the 2010 NPT Review Conference on 3 May: “We need more examples of what can be achieved – not more excuses for why it is not possible.” The UKNI, while in the greater scheme of things quite modest, is a fine example of what can be achieved when political leadership is consistent and sustained.

— Lord Browne of Ladyton, UK Secretary of State for Defence (2006–2008)

2. Introduction

When VERTIC undertook to write up its observations on the so-called UK-Norway Initiative on verified warhead dismantlement its staff imagined a straightforward report filled with details on the Initiative, but not much else. Over time, however, it became clear that the only way to grasp the Initiative's significance was to place it within its proper context. The UK-Norway Initiative was not the first effort to look into dismantlement verification; nor will it be the last. Comparing the Initiative's strengths and limits with initiatives of the past seemed a good way to highlight its unique features, to explore which verification solutions might work in real-world scenarios, and to identify gaps in the current body of research.

The report evolved into a story, almost a limited history of inspection exercises over the last fifty years. It almost became a history of nuclear arms control verification itself, charting strands of thinking from the height of the Cold War to present day. It was felt that the rich historical experience of previous research into dismantlement verification has not been accorded the attention it deserves, nor ever consolidated in one place. For a casual observer looking at any one example in isolation, this wider body of knowledge could be easily missed. The report is based on a wide variety of different primary and secondary, government and non-governmental, sources—some recently declassified. Aside from a few instances of personal communication with involved participants, all sources consulted for this report are freely available in the public domain.

Surprisingly perhaps, in light of the stakes involved, there has not always been a sense of urgency surrounding research on nuclear warhead verification. Given the many tens of thousands of nuclear weapons in existence during the long decades of the Cold War the world is remarkably fortunate that such devices have only ever been used twice in anger. The shocking destructive power of the atomic bombs dropped on Hiroshima and Nagasaki in August 1945, forerunners to the vastly more powerful thermonuclear weapons developed and tested as the post-war chill of US-Soviet rivalry set in, revealed in the starkest and most brutal of fashions that mankind truly had become, as Robert Oppenheimer reportedly once said, a 'destroyer of worlds'. Never in the field of human conflict, as Winston Churchill might have put it, was so much suddenly at the mercy of so few.

Science and technology brought nuclear weapons into existence. And science and technology will have an important role in their abolition. But science and technology can do little to change the political conditions for disarmament. Indeed, one will often hear arguments to suggest that nuclear disarmament is dependent on a fundamental shift in world affairs. That somehow the likelihood of large-scale conventional war has to be significantly lessened, or even outright eliminated, before nuclear disarmament can come about. Proponents of this way of thinking often claim that nuclear weapons' deterrence value—the rational knowledge that aggression will lead to the certain annihilation of the aggressor—has helped preserve a relative peace among nations since the Second World War. Nuclear disarmament may not be desirable, they argue, if it comes at the expense of world peace. And while there is no way to prove this argument (as there is no way to disprove it), it is probably fair to assume that most policymakers in the nuclear-armed states of the world would prefer known stability over potential instability.

Similarly difficult logic problems exist in the realm of verification. Ever since the days of Jerome Weisner, science advisor to Presidents Kennedy and Johnson, it has commonly been assumed that verification demands will increase as nuclear stockpile numbers fall. In 1961, Weisner argued that as zero approached, the quantity of undisclosed weapons and militarily-significant amounts of fissile material would get progressively smaller and verification demands progressively, and correspondingly, larger. 'This argument is certainly intuitively appealing', note James Acton and George Perkovich of the Carnegie Endowment for International Peace in their 2008 study *Abolishing Nuclear Weapons.*[1] Indeed, it is a point repeated so often by so many as to have become almost a truism. As David Cortright and Raimo Vayrynen wrote recently: 'It is clear that progress towards nuclear zero will require more intrusive methods of verification . . . The closer the world moves towards nuclear zero, the greater the degree of transparency and openness that will be required from all governments.'[2] It is a logical point. In reality, however, while stockpile numbers have fallen significantly since the end of the Cold War verification demands have swung back and forth.

Consider the three major US-Russian arms pacts of the last two decades. The 1991 Strategic Arms Reduction Treaty (START) brought with it a diverse and complex set of verification provisions. The 2002 Treaty on Strategic Offensive Reductions (SORT) contained no verification provisions whatsoever. More recently, with the 2010 'New START' accord, the tide has turned once again, bringing stringent verification back into fashion. So while Jerome Weisner's rationale is sound enough in theory, arms control and disarmament practice, thus far, seems to tell a story all of its own.

Verification exercises such as the UK-Norway Initiative, however, do not take broader philosophical questions into consideration. Rather, they tend to look at a rather narrowly defined flow of events—the movements of fissile materials or weaponry—and attempts to identify measures by which such flows can be made more transparent. This is always done through an apolitical scientific exchange. 'Scientists can talk', their participants may say, 'while the politicians quarrel'.

Scientists have a mixed impact on arms control processes. Sometimes, their attempts to 'depoliticise verification', as Nancy Gallagher puts it in her seminal study *The Politics of Verification,* merely represent 'cynical strategies employed to gain a stronger bargaining positioning'. Sometimes, however, their efforts are 'sincere attempts to show that scientists from both sides could agree on some verification questions.' Science and technology cannot exist in a political vacuum, she argues. 'Without reliable political guidance . . . technical experts had either to avoid core controversies or to propose solutions that made sense given their own assumptions but that lacked support from policy makers who thought differently about arms control and verification'.[3] In many cases, however, scientific and technical endeavours help to light the path toward verified nuclear disarmament.

On which point, it should be recalled that, while the dismantlement of warheads is one thing, verification of dismantlement is quite another. As a means of building trust and confidence between states, however, dismantlement is of limited value unless it is done in a transparent and verifiable manner. And herein lies a problem that will become a running theme throughout this report: how to balance verification needs and inspector confidence with the reality that, for reasons of national security and non-proliferation, nuclear weapons and weapons complexes operate under thick cloaks of secrecy. Given these factors, and the significant differences between the weapons complexes and dismantlement processes of different nuclear-armed states (broad commonalities notwithstanding), developing verification methodologies for warhead dismantlement is no small feat.

Studies of dismantlement verification examined in this report go back many decades. They are presented chronologically, like a historical study, before finishing with a description of the UK-Norway Initiative. Readers only interested in the UK-Norway Initiative can of course skip ahead, but will in doing so miss the lessons learned from previous initiatives. All work presented in this report builds on the work of predecessor initiatives. Recent initiatives disregard those aspects of past exercises that did not work, while they repeat and refine those aspects that did.

In designing verification exercises, believable scenarios are crucial. To a considerable extent, exercise outcomes are directly dependent on the scenario itself. The more realistic the scenario is, the more valuable its outcomes will be. A scenario designer has to understand and recreate real-life conditions for the exercise participants. For nuclear disarmament exercises this involves grasping the nature of a 'treaty limited item' as well as the environment that the exercise will take part within. This is not a challenging problem if a nuclear-weapon state is running an exercise within real facilities with security-cleared personnel. However, creating the environment becomes more difficult if uncleared personnel are involved, especially if those personnel are from another state. Creative thinking is then called for. One solution is to create an unclassified environment that simulates a classified one (this solution was preferred by the UK-Norway Initiative). Realism is maintained by creating artificial classifications on the exercise site itself, and by creating a fictitious treaty limited item. Both the site and the item must share essential attributes (such as classified properties or features) with the real sites and items, but can otherwise take any shape or form.

The UK-Norway Initiative invested considerable time and effort in creating a believable training ground. Its participants did so by reviewing real dismantlement processes, and then by selecting and recreating features that were believable enough for exercise purposes, but which contained no real-life classified properties. In a similar fashion, this report begins with an overview of real dismantlement processes. It is designed to give a flavour of the setting, and does not purport to be an authoritative description of the processes themselves.

The next section of the report then reviews a number of significant verification exercises that, in one way or another, have influenced VERTIC's thinking throughout its participation in the UK-Norway Initiative. It should be mentioned at this point that this report does not necessarily reflect the thinking of the UK or Norwegian officials who took part in the project. This report starts with exercises that are nearly fifty years old, and moves forward in time from that departure point.

Back in the 1960s, then, at the height of the Cold War, the United States undertook a little-publicised verification exercise known as Field Test FT-34, geared heavily toward developing metrics for concepts such as verifiability and intrusiveness. With meticulous attention to detail, scientists and military men working across four different US nuclear sites charted the probabilities of diversion and of revealing classified information at various levels of inspection intrusiveness. Some of the project's conclusions are intuitive and reappear in later studies (such as the increase in inspector confidence with increasing levels of access). Others, such as the exponential rise in the number of classified items revealed as access levels increase, are more distinctive. But all highlight the importance of carefully managing any inspector access to dismantlement facilities.

The 'Black Sea Experiments' conducted in the late 1980s were a verification exercise anomaly. In these instances, US non-governmental scientists were allowed to get close to an operational warhead, located on an active service Soviet naval vessel. What was spectacular about the exercise was that it allowed full measurements on the warhead in question. No attempts were made to filter the measurement through a so-called 'information barrier' or to otherwise use a 'blinded' sensor. While the Black Sea Experiments had no sequel, and arguably would not be allowed to transpire today, they clearly show that a state's tolerance to intrusiveness shifts over time.

Some years later, in 1997, a study by the US Department of Energy concluded that moderate inspector confidence in the dismantlement of a nuclear warhead is achievable without the need for two sides to engage in an exchange of classified information. But while a generally positive report, it raised an interesting problem also: namely, that determining whether an item presented for dismantlement is in fact a genuine warhead is, on balance, very difficult. Chain-of-custody of the object may have to be established very early on, it suggested, perhaps even as early as deployment sites, if this uncertainty is to be overcome. This observation would later reappear in the UK-Norway Initiative itself.

Around the same time as the Department of Energy's deliberations, the joint Trilateral Initiative between the US, Russia and the International Atomic Energy Agency (IAEA) was exploring the concept of the information barrier—a device that would allow nuclear-weapon states to invite IAEA inspectors to take measurements of nuclear weapon components without gaining access to classified design information. Interestingly, the same measurements had been allowed in the Black Sea Experiments without this technology. Information barrier technology was designed to provide simple 'pass/fail' readings based on a set of unclassified, pre-agreed attributes of an item under inspection. For six years work amongst these three parties continued, before the project was wound down in 2002—but the legacy and obvious potential of the information barrier lived on, resurfacing once again as part of the UK and Norway's joint efforts.

As the Trilateral Initiative was drawing to a close, the Atomic Weapons Establishment (AWE) in the United Kingdom was embarking upon its own dedicated arms control verification programme. Over time, this programme developed into a structured research agenda that directly contributed to the UK-Norway Initiative's birth. A report of its consolidated findings, presented in the form of a working paper to the 2005 Nuclear Non-Proliferation Treaty (NPT) review conference, firmly established the UK as the most forward-leaning of all the nuclear-weapon states in the field of nuclear disarmament verification research.

In the aftermath of that ill-fated review conference, the UK and Norway came together—with the assistance of VERTIC—to establish a joint research programme looking into the technical requirements of warhead dismantlement verification in the unique context of nuclear-weapon state (NWS) and non-nuclear-weapon state (NNWS) cooperation. A sizeable portion of this report is devoted entirely to the Initiative. As noted above, readers not interested in the conclusions of earlier verification efforts may skip ahead, as previous sections can be read more or less as stand-alone contributions.

Verified warhead dismantlement will inevitably form an essential aspect in fulfilling multilateral disarmament obligations undertaken as part of Article VI of the Nuclear Non-Proliferation Treaty (NPT). It is in this context that the UK-Norway Initiative got underway. In part, the UK-Norway Initiative was envisioned as a confidence-building measure to narrow the gap between NWS and NNWS on disarmament issues, in a period of mounting scepticism about NWS's seriousness in relation to their NPT disarmament obligations.

Research under the Initiative proceeded along two strands: one on information barrier technology, building on research undertaken during the Trilateral years; and one on 'managed access' methodologies for inspection personnel. One of the stand-out features of the Initiative was its exploration of real-world solutions through the holding of simulated exercises to test verification methods and techniques in realistic settings and identify areas where further research was required.

In organising the Initiative along these strands, it sought to tease out lessons from the interaction of NWS and NNWS on the verification of warhead dismantlement. And as the first example of collaboration between a nuclear and a non-nuclear-weapon state on the verification of warhead dismantlement, the UK-Norway Initiative broke important new ground. The results were encouraging, suggesting that NWS-NNWS cooperation in this specific area of nuclear arms control is not only possible but useful also. Moreover, nothing in the Initiative led to a conclusion that the verified dismantlement of nuclear warheads is not a technically feasible goal within acceptable levels of confidence.

The final part of the report is dedicated to conclusions drawn both from the Initiative itself and from all those studies that went before, so attempting to put the UK-Norway Initiative in its proper context.

3. Inside the Dismantlement Process

To understand dismantlement verification needs and procedures, it is first helpful to understand what, in a general sense, the dismantlement process itself entails. Although most nuclear weapons follow the same general design principles, there is no single blueprint according to which a nuclear weapon must be built. Nuclear arsenals nowadays consist of weapons of varying types, classes and designs. Moreover, diversity in design also extends across the world's various nuclear-armed states. Most modern nuclear weapons, particularly those in arsenals of the five NPT-recognised nuclear-weapon states, work by imploding a spherical 'pit' of fissile material—the 'primary' stage—in order to induce fusion in an adjacent 'secondary' chamber packed with fusion fuel. Typically constructed of highly enriched uranium and/or plutonium, compression of the pit is achieved through the simultaneous detonation of an outer shell of high explosive lenses. In contrast, some nuclear weapons follow a more simple design, relying only on fission in the pit. In other words, these devices, such as the pair of weapons dropped on Japan and those developed (and subsequently dismantled) by South Africa, do not contain a secondary. North Korea's nuclear explosive devices are also thought to be based on fission alone.[4]

Given the many shapes and sizes in which nuclear weapons come, dismantlement processes are highly varied—both in the step-by-step process of taking a warhead apart, and in the time required to do so. Moreover, different countries operate different systems for warhead dismantlement. Despite that, some steps are common to all dismantlement chains and these will be briefly discussed here.

According to the US Department of Energy, warhead 'dismantlement' refers essentially to the separation of a weapon's high explosives from its fissile material components.[5] The arrangement of nuclear materials, explosives and various other non-nuclear parts essential to the detonation of a nuclear warhead tend to be collectively referred to as a weapon's 'physics package'. To dismantle a nuclear warhead, the physics package must first be removed from the bomb casing; only then can its constituent parts be separated and the bomb disarmed. The following section looks at dismantlement processes in the US and Russia, the two nuclear-weapon states with most experience in dismantlement, and the two for which information is most available, though not in any great quantity, in the public domain. This is not to suggest, however, than other states either do or would follow the same steps and processes.

Differences aside, however, all dismantlement processes will necessarily entail a number of common stages. First, a warhead must be retired from active service and transported, perhaps via interim storage, to the facility at which it will be dismantled. At a dismantlement facility, two main operations are carried out: extraction of the physics package from the weapon's casing; followed by disassembly of the physics package into fissile material components, high explosives and other non-nuclear parts. After disassembly of the physics package is complete, its various components are then disposed of in ways best suited to their type and properties.

3.1 Retirement and transportation to disassembly plant

The first stage in any dismantlement chain is for a weapon to be retired from service. In the US, once nuclear weapons are retired they are separated from their delivery systems and moved to Department of Defense (DoD) storage. There, they await collection and transport to the main US dismantlement facility at Pantex, Texas, by the DOE's Transportation Safeguards Division.[6] As soon as weapons are picked up from a Pentagon-run storage facility, custody passes from the DoD to the DOE.[7] Weapons arriving at Pantex are taken first to the plant's staging area and temporarily placed in one of the storage magazines (earth-covered bunkers) located there.[8]

Within 72 hours of a warhead's arrival, gamma spectrometry and/or neutron detection verification is performed by Pantex staff.[9] Radiographic safety inspections, to determine the status of newly arrived weapons and their component parts (e.g. position of switches, status of valves, presence/absence of cracks in the high explosives, integrity of components), are also conducted prior to the commencement of disassembly.

In Russia, as far as can be deduced, after a retirement decision is made, Russian nuclear warheads are separated from their delivery platforms and placed inside storage and transportation containers—at which point custody is transferred to officers of the Russian Ministry of Defence's 12th Main Directorate, an organisation responsible for managing nuclear warheads not associated with delivery systems. A batch of retired warheads is then transported (usually by rail) to a central warhead storage facility. Then, according to a dismantlement schedule, retired warheads are delivered to an assembly-disassembly facility, where they are kept in a storage/staging area until dismantlement is ready to begin.

Once a containerized warhead is received at a warhead disassembly plant, facility staff—in the presence of representatives from the Ministry of Defence and the corresponding warhead design institute—reportedly open the container, conduct entry radiological control of warhead surfaces and verify documentation. A decision on whether or not to authorize dismantlement is then made, and if the go-ahead is given, the warhead enters the actual disassembly chain.[10]

3.2 Mechanical disassembly of warheads

The second stage in the dismantlement process is for warheads to be removed from storage and into those specific locations where mechanical disassembly takes place. Mechanical disassembly generally refers to the separation of the physics package from the weapons' casing. In the US, warheads are moved from storage to disassembly bays to undergo mechanical disassembly, which includes:

- Removal of the warhead from its shipping container
- Removal of non-nuclear components (e.g. parachute canister, tail fins, pre-flight packages etc.)
- Removal of the warhead's Arming, Fusing & Firing (AF&F) component
- Removal of tritium containers (if not already done), and
- Removal of the nuclear physics package containing the weapon's nuclear components and high explosives

As mentioned above, however, warhead design features vary between types and it should therefore be noted that the above list is not all-inclusive, nor do all weapons have all the above components. Typically, two to four bays are associated with mechanical disassembly for each warhead programme.[11]

Information available in the public domain on Russian procedures for the dismantlement of their warheads is, in comparison to the US, even scarcer. What little is known is that the Russian dismantlement process—which takes place in specialized concrete cells—involves the following steps: (1) separation of the physics package from the warhead; (2) removal of the primary from the physics package; (3) separation of the fissile materials contained in the primary and secondary; (4) packaging and temporary storage of fissile materials; and (5) mechanical disassembly of non-nuclear parts.[12]

3.3 Disassembly of the physics package

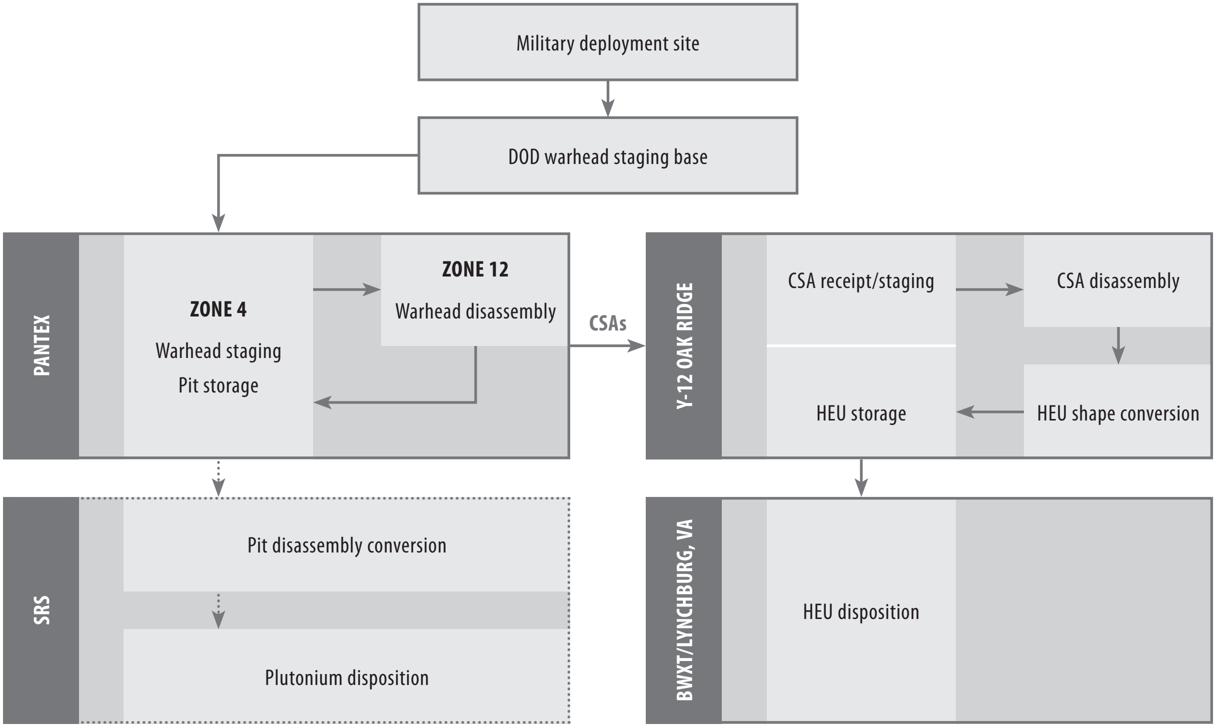
The third stage in the dismantlement process is for the components of a weapon's physics package to be separated out. This includes the further disassembly of the physics package into fissile materials, high explosives and other components.

In the US, once mechanical disassembly is complete (i.e. once the physics package has been removed), the physics package is then moved to one of Pantex's dismantlement cells (or 'gravel gerties', as they are more colloquially known) where the warhead's high explosives, secondary and pit are separated. After that, the warhead is considered to be fully dismantled and ceases to exist for accounting, and nuclear explosive safety, purposes. Not all warheads go from bays to cells, however. Some older warheads (ones lacking the safety features of their modern cousins) are completely disassembled in cells.[13] The dismantlement process takes from five days to three weeks to complete, depending on the type of warhead being dismantled and the workload of facility staff.[14] High explosive removal alone can take a day or longer per warhead for certain warhead types.[15]

3.4 Waste streams and disposition

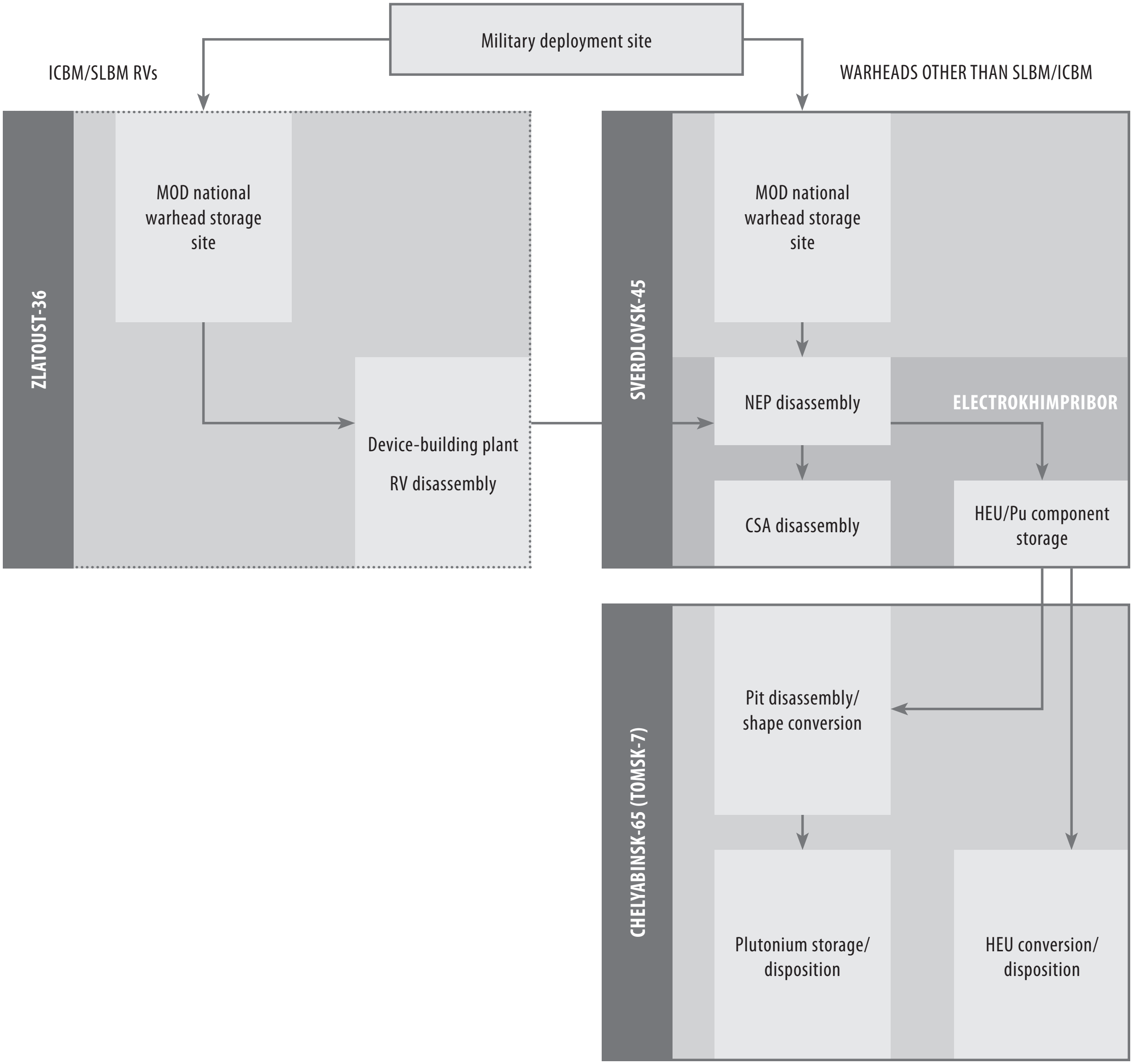
At this stage, disassembled warhead components have to be disposed of in some manner. In the US, when the nuclear physics package has been taken apart, extracted nuclear components are placed in storage until they are ready to be disposed of or transported to other DOE weapons complex facilities around the country.

Figure 1 The warhead dismantlement process in the USA



Note: BWXT = BWX Technologies; CSA = canned sub-assembly (secondary); DOD = Department of Defense; HEU = highly enriched uranium; SRS = Savannah River Site.
Source: Oleg Bukharin, SIPRI.

Figure 2 A hypothetical scenario of warhead dismantlement in Russia



Note: CSA = canned sub-assembly (secondary); HEU = highly enriched uranium; ICBM = intercontinental ballistic missile; MOD = (Russian) Ministry of Defence; NEP = nuclear explosive package (i.e. physics package); Pu = plutonium; RV = re-entry vehicle; SLBM = submarine-launched ballistic missile.
Source: Oleg Bukharin, SIPRI.

Secondaries are sent to the Y-12 plant in Tennessee for final disassembly and pre-disposition storage.[16] Sealed plutonium pits are placed inside steel storage containers and moved into storage at Pantex.[17] All other parts removed from dismantled warheads, if not intended for re-use, are categorized, disfigured and/or rendered unusable (if required to satisfy classification and/or non-proliferation concerns), and staged for disposal.[18] (These efforts require significant portions of the Pantex site, totalling more than 14,000 square metres). High explosives are destroyed through open-air burning on-site at Pantex.

In Russia, after interim storage at dismantlement plants, containers holding recovered HEU and plutonium components are moved to fissile material complexes where HEU components are reduced to metal shavings and converted to purified uranium oxide powder, which is then transferred to other facilities for fluorination and down-blending.[19] Plutonium, on the other hand, likely remains in storage pending its disposition as plutonium-uranium mixed oxide fuel in nuclear power reactors. Non-nuclear components that were in direct contact with fissile materials are cemented inside containers and disposed of on-site. Other non-nuclear components are 'sanitized' (i.e. deformed), then recycled or disposed of. As in the US, extracted high explosives are destroyed through burning.[20]

4. The Early Days: Field Test 34 (1967)

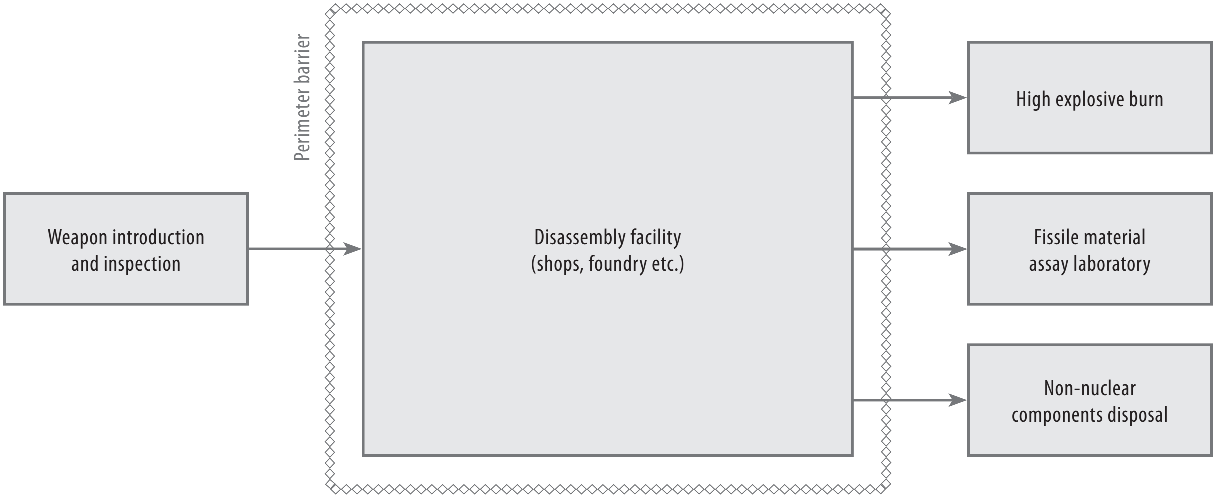
Over the course of a four-month period from 21 June to 20 October, 1967, the US Department of Defense (DoD) and the US Arms Control and Disarmament Agency (ACDA) conducted a joint investigation into the 'Demonstrated Destruction of Nuclear Weapons', a project designated Field Test FT-34. Its purpose, as set out in the test's declassified Final Report,[21] 'was to develop and test inspection procedures to monitor the demonstrated destruction of nuclear weapons.' This was in line with US proposals around at the time to transfer up to 60,000 kilograms of weapons-grade uranium-235 to non-weapons uses.[22] The test (undertaken as part of the DoD and ACDA's jointly funded Project Cloud Gap)[23] was an investigation of inspection methodologies that made use of radiation detection equipment, X-ray plates of weapons and laboratory analyses of extracted fissionable material.

FT-34 was conducted across four US Atomic Energy Commission (AEC) plants—Pantex (Texas), Rocky Flats (Colorado), Paducah (Kentucky) and Y-12 (Tennessee)—and involved 40 nuclear weapons scheduled for normal retirement as well as 32 fakes.[24] Since there was (and still remains) no single facility in the US where all operations associated with the retirement and dismantlement of nuclear weapons took place it was necessary to spread the test over the four separate locations—a strategy not without its logistical difficulties (even if the use of actual AEC plants did add an important layer of realism). Inspection teams of different sizes working under different levels of access monitored the destruction of the weapons presented to them and assayed the fissile material contained therein. From these activities, inspectors were able to gather evidence relating to the amount of classified information revealed, and the credibility of the dismantlement process tested.

4.1 The three stages of dismantlement

FT-34 was based on a theoretical 'basic concept' of demonstrated destruction involving three principal stages: weapon introduction; weapon disassembly; and component disposition.[25] Ideally, all stages would be carried out at a single facility established for the specific purpose of disassembly and disposition, based on the arrangement shown in the diagram below.

Figure 3 A possible dismantlement facility arrangement drawn up ahead of the FT-34 exercise



Source: Annex D to the Final Report, page 15.

At the first stage, a number of weapons—exactly how many would likely depend on safety considerations—would be brought together inside an enclosed compound for 'cursory inspection by adversary [for which, read Soviet] inspectors.' At this stage, weapons would still be enclosed within bomb cases or in the nose sections of re-entry vehicles. (Delivery vehicles, though, would not be included.) Inspectors would, according to the concept, be limited to making only visual observations, counting and perhaps weighing weapons. No direct access would be permitted to any internal parts, nor would it be permissible for inspectors to use radiation measuring instruments. Before any weapons were moved into a facility for disassembly, inspectors would be allowed to make a walkthrough tour and visual inspection of the facility in question, in order to assure themselves of the absence of nuclear weapon components and materials prior to the introduction of the weapons to be dismantled.

During the disassembly stage, inspectors would then be required to remain outside for the entire process—from the introduction of weapons to the disassembly facility to the later removal of fissionable material and other components. Only host nationals would be allowed inside a dismantlement facility during disassembly. Entry for others into this area could be permitted after a whole batch of weapons had been processed, though it was thought that inspectors probably ought to be allowed to inspect non-weapon materials (excluding documents) moving in and out of the facility while weapons disassembly was taking place. In that way, inspectors could observe that no new weapon materials and/or explosives were being introduced during the dismantlement process and that no salvage of nuclear and/or other materials was taking place either.

After disassembly, the high explosive and other burnable components would be removed from the facility, weighed and burned under observation by inspectors. Recovered fissile material would be weighed and assayed, with the assay either conducted or observed by inspectors. Remaining non-nuclear components would be weighed and disposed of in some mutually agreed manner (ocean burial, for instance). Throughout the burning, assay of fissile material and destruction of non-nuclear components the material presented for weighing and inspection would be correlated—in theory—with the original batches of weapons. After completion of these processes, inspectors would again examine the interior of the facility where disassembly took place in order to determine that no weapons or components had been withheld.

As noted in the test's Final Report, the disposition of warhead materials resulting from dismantlement presents 'a number of potential difficulties' because, although this stage offers 'prime opportunities' to assure inspectors that weapons are indeed being destroyed, it also offers 'subtle possibilities for the disclosure of sensitive information.'[26]

4.2 Test objectives

Of primary concern during FT-34 was a determination of the amount of classified information that might be revealed were inspectors from the Soviet Union allowed to monitor the dismantlement of US nuclear weapons. Indeed, it appeared—uncomfortably—that for Soviet inspectors to be convinced that real nuclear weapons were being destroyed, some classified information would have to be revealed to them. The objectives of the test were built around both this problem and the need to elucidate and investigate the practical problems of verified dismantlement. Specifically, the four objectives of FT-34 were as follows:

- To determine the extent to which the proposed method of demonstrated destruction revealed classified weapon information.
- To evaluate the effectiveness of the tested procedures in terms of convincing the test inspectors that real nuclear weapons were being destroyed.
- To evaluate the practicability and effectiveness of the proposed methods and to suggest and implement possible improvements.
- To identify operational, technical, classification, safety and security problems arising during the test.[27]

4.3 Inspection exercises

FT-34 took the form of three general exercises: (1) an overall test of the demonstrated destruction of nuclear weapons conducted in phases across all four AEC sites; (2) a test focusing on the analysis and assay of uranium conducted by selected military inspectors at the Y-12 plant; and (3), another test of uranium analysis this time conducted by a small team of Y-12 scientists.

Inspectors for the first two exercises were provided by the DoD. All but one were serving military officers (the exception was retired Air Force) and all had some prior training or experience in either nuclear weapons or chemistry or both. Inspectors received ten days training prior to inspection operations. As noted in the Final Report, this training included 'familiarization with the purpose and objectives of the test, refresher orientation on US nuclear weapon design and hardware, identification of the classified aspects of nuclear weapons, test procedures, operation of test equipment, analysis of fissionable materials, data forms, safety practices, security requirements, and administrative matters.'[28] Additional training was given at each site in relation to particular procedures followed and equipment used.

During the overall inspection exercise—exercise one—a variety of inspection methods were tested for their usefulness in monitoring facilities, weapons and weapons components. Inspectors recorded their observations on prepared data forms. Some inspectors also made sketches, took photographs and searched for fissile material with Geiger counters. Weapons were measured, weighed, sketched and photographed by inspectors, as were non-nuclear components and residue. During the analysis and assay stages, normal laboratory facilities, materials and equipment were used and analyses were conducted 'just as analyses are normally conducted in AEC facilities' on fissionable materials. Operations included mass spectrometry, chemical analysis and emission spectrometry.[29]

So as to avoid interfering with normal plant operations at the four sites, special areas were designated at each site for the purposes of FT-34 activities. Sensitive areas not associated with the field test were shielded from inspectors' views—using barriers and curtains in some cases—while specific routes to and from inspection areas were also defined to keep inspectors from accidentally straying into sensitive parts of the site.

Evasion was included as part of all test exercises. Since the US proposal for transferring fissionable material to peaceful uses involved obtaining material of this kind from nuclear weapons, two possible approaches to evasion presented themselves. The first would be to set aside for peaceful uses less fissionable material than advertised, while the second would be to obtain the material from sources other than weapons. Attempts to evade inspectors centred on these two possibilities for misdirection. No intentional harassment of inspectors was tested during FT-34.

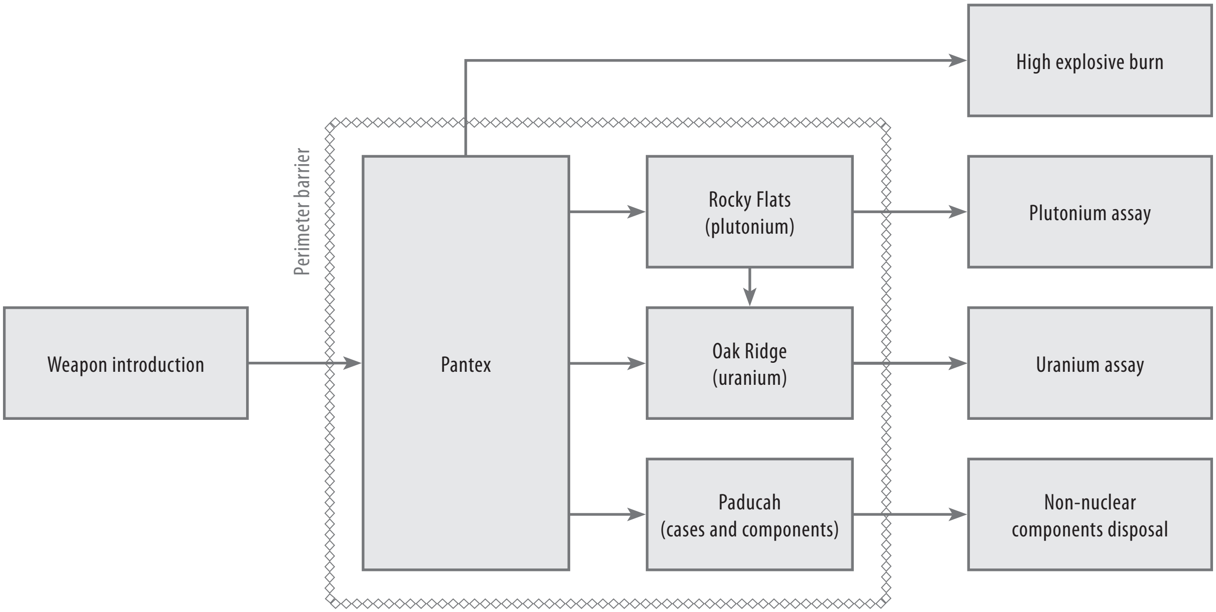
4.3.1 Exercise one: the overall destruction exercise

This was an exercise 'designed to simulate as closely as possible the inspection of all phases of the demonstrated destruction of nuclear weapons' from an initial inspection of the destruction facilities to the final assay of the recovered fissile material.[30] It was conducted in sequence across all four AEC facilities 'in a manner intended to simulate as closely as practicable the operation of a single facility.' Nonetheless, as an annex to the main report noted: 'The use of four different facilities and the requirement not to interfere with normal plant operations introduced some artificiality into the overall test.'

At Pantex, weapons disassembly and the burning of explosives and other burnable components was carried out. Rocky Flats was used for the recovery and assay of plutonium; Y-12 for the recovery and assay of uranium. Paducah was used for the disposition of remaining non-nuclear components. Four identical batches of weapon shapes, totalling 72 weapons (40 real, 32 fake, as noted above) in all, were subjected to inspection. The flow of weapons and materials through the four facilities used is shown below.

For this exercise, five phases were involved, some of which overlapped in time or location. 'Throughout each of these phases, inspection teams made extensive records of everything they observed including dimensions

Figure 4 Flow chart showing division of the dismantlement process during FT-34



Source: Final Report, page 40.

and features of tooling, weapon shapes, and destruction products. With these observations, inspectors attempted to detect classified information revealed and to determine the credibility of the demonstration.'[31]

Phase one consisted of walkthrough inspection tours of each of the four facilities, conducted before and after the processing of each batch of weapons or material. During these tours inspectors 'looked for indications that the facility was equipped to process bona fide weapons, searched for indications that nuclear material had been prepositioned, and recorded any classified information that was revealed.' The second phase was the inspection of the weapon shapes presented for destruction. Any classified information revealed was again recorded by inspectors, while inspectors now also tried to determine the credibility of the weapon shapes or material.[32]

The third phase was the burning of the high explosives and other burnable components to result from weapon disassembly. Phase four was the destruction, under inspection, of the remaining non-nuclear components by smelting and/or burial, or by packaging and simulated disposal. The fifth and final phase was the assay of the recovered fissile material at Y-12 (for uranium) and Rocky Flats (for plutonium). Similar procedures, though with different equipment and techniques, were used at both locations. Sample purity was determined by chemical titration, impurities were analysed using emission spectroscopy and isotopic content determined by mass spectrometry.

Throughout phases two to five inspectors maintained records of the weights of the materials being processed. The total outgoing weight of burnable materials, non-nuclear components and fissile material was compared against the incoming weight of weapons presented for destruction to determine the net weight balance for the process. (Time and safety considerations necessitated that inspectors not perform the actual weighing but instead spot-checked the weights as determined by plant personnel.)

For this exercise, in order to test the effects of team size, 26 inspectors were divided into two 13-man groups—codenamed LIMA and MIKE—within which they were further subdivided into a pair of two-man and a pair of four man teams under a chief inspector for each group. In addition, to investigate the effects of varying rights of access, the degree of inspector access to weapon shapes and disassembly facilities during the overall destruction exercise was tested at multiple levels.

During the walkthrough phase, low access inspection teams were allowed to only observe and to make notes and sketches. By contrast, high access teams were allowed to take measurements, photographs and Geiger counter readings in order to check for pre-positioned fissile material and to detect particles of nuclear material that could, when assayed, reveal classified information.

During phase two, at which weapon shapes were presented, four levels of access were tested. At the first level (A1), inspectors examined the weapon shape exteriors and determined weights, the locations of some external features, centres of gravity and dimensions. At the second highest level (A2), inspection teams were also allowed to peer inside opened access doors on the weapon shapes and to use Geiger counters at the surfaces of the shapes in order to determine the location of any radioactive material. At the next level (A3), inspectors could also take photographs, use neutron counters to detect plutonium presence and gamma spectrometers to determine the types of radioactive material located by Geiger readings. At the fourth and highest access level (A4), inspectors were additionally permitted to examine X-ray plates of the weapons.

During the burn phase, low access teams were permitted to observe the weighing of closed boxes containing the high explosives and other burnables and could observe the actual burning. High access teams were also allowed to look inside and photograph the contents of the box. Both levels of access permitted the teams to examine the post-burn residue. Examination of the post-burn residue allowed inspectors to be further assured that components removed from warheads had been destroyed in an irreversible manner.

Four access levels (A1-A4) were again tested during the disposal of the non-nuclear weapon components. At the first level inspectors observed metal ingots from the smelter, closed boxes containing various components, and several sealed weapon cases that could not be smelted and were too large for packaging. Weights of some material were checked and the burial of some packaged components was observed. At the second level the teams were also allowed to look into opened packing boxes and weapon cases from a distance of around ten feet. At the third level inspectors could also visually examine the contents of the packing cases displayed on the floor. At the highest level of access inspector teams were also allowed to handle, measure and photograph these components.

During the fifth phase, the assay of recovered fissile material, low access teams observed laboratory technicians performing the assay and were not allowed to ask questions while high access teams performed all operations themselves (except for those not permitted by safety regulations).

Figure 5 Table showing evasion, access and team size variables for each of FT-34's five dismantlement phases

	Overall exercise				
Variable	**Walkthrough**	**Shape inspection**	**Burn**	**Non-nuclear disposal**	**Fissile material assay**
Access to operation	Low, High	A1, A2, A3, A4	Low, High	A1, A2, A3, A4	Low, High
Team size	2 man 4 man	2 man 4 man	2 man 4 man	2 man 4 man	2 man 4 man
Evasion	No	Yes	No*	No*	Yes

* Although no new evasion was attempted during these phases, some components inspected came from fake weapons introduced during the shape inspection phase.
Source: Annex D to the Final Report, page 19.

Of the four batches of nuclear weapons presented to the LIMA and MIKE inspection groups, each contained a mixture of real and fake weapons.[33] Four fake weapon types were introduced into the exercise. Three were expected to be detected at successively higher inspection access levels; the fourth was expected to remain undetected at even the highest level. During the assay of uranium at Y-12, evasion was performed by remotely adjusting the mass spectrometer to indicate a two per cent higher than actual proportion of U-235 in half of the samples. Thus, inspectors would be led to believe that more U-235 had been produced than was in fact the case. During the plutonium assay at Rocky Flats, evasions were arranged through concealed material substitutions and modified laboratory equipment to indicate a lower than actual level of purity.

4.3.2 Exercise two: the special uranium assay exercise

Due to the importance, from the point of view of an adversary inspector, of making sure that US weapons-grade U-235 transferred to peaceful uses is transferred in the amounts and purities advertised, FT-34 placed particular importance on investigating the analysis and assay of uranium. Thus, 'in order to investigate further some of the problems associated with [this],' once the first exercise had been concluded, eight selected inspectors from the LIMA and MIKE groups were rearranged into four new teams of two men each for a special assay exercise using specially prepared samples of uranium. Two of these new teams were composed of men skilled in chemical analysis while the other half were made up of relatively unskilled personnel—which again allowed the effects of team composition to be tested. And as before, access was also set at different levels. One skilled and one unskilled team were granted a high degree of access by being allowed to perform all operations; the other two teams were restricted to only observing laboratory technicians perform the assay.

The primary purpose of this exercise, and the next (involving laboratory staff), was to investigate the effects of evasion when using a host-controlled laboratory. Additional purposes were to test the effect of changing access rights on inspection performance, hence the varying levels, and to investigate the effect of team composition, hence the division of teams into experienced and inexperienced groups. 'All of the teams were subjected to extensive evasion practices during the assay of most of the samples.'[34]

4.3.3 Exercise three: the scientists' uranium assay exercise

The third and final exercise—the scientists', or contractors' assay—involved a new team of three professional laboratory scientists from the Y-12 plant repeating the special assay analysis using the same samples and subject to the same evasion techniques. One was a specialist in mass spectrometry, one was a specialist in chemical analysis, and one was a specialist in emission spectroscopy. They worked only as a high access team (i.e. performing all work themselves).

Evasion measures for exercises two and three involved techniques designed to make the uranium samples under investigation appear to possess slightly more uranium than was in fact present and to increase the apparent ratio of U-235 to other uranium isotopes. Chemical purity tests were evaded through the addition of impurities to the samples and by altering the balance used for weighing the samples. During the emission spectroscopy, the added impurities were disguised by, for instance, altering the measuring equipment. The determination of isotopic ratio by mass spectrometer was altered either by the use of filaments modified to alter the ratio of plutonium isotopes obtained (at Rocky Flats) or by remotely changing the readout (at Y-12).

4.4 Results

The first objective of the FT-34, it may be remembered, was to determine the amount of classified weapon information revealed by a demonstrated destruction. Throughout the overall destruction exercise, a total of 112 items of classified information were revealed to inspectors. Since determining the extent of classified information release was one of the test's principal objectives, no attempt, it should be noted, was made to hide or

Figure 6 Table showing amount of classified items exposed during FT-34 at each stage of the demonstrated dismantlement

		Number of items available			
Site	**Ops**	**Low**		**High**	
	Access	**A1**	**A2**	**A3**	**A4**
Pantex	Walkthrough	5		5	
	Weapon inspection	2	4	6	58
	High explosives burn	4		11	
Rocky Flats	Walkthrough	4		4	
	Disposal	1		1	
	Assay	1		1	
Paducah	Walkthrough	0		0	
	Component inspection	2	7	16	16
Y-12	Walkthrough	12		13	
	Assay	3		3	
Total		**34**	**41**	**60**	**112**

Source: Final Report, page 75.

conceal such information. Indeed, as noted in the report: 'Many classified items were revealed because no attempt was made to protect them.'[35] Teams operating at the highest cumulative access level were exposed to all 112 items. The lowest cumulative access level revealed 34 items (with 41 and 60 items being revealed at the second and third highest levels respectively, see chart above). Classified information was, therefore, revealed even at the lowest levels of access. (In one form or another, classified information was also revealed at each of the exercise's five phases.)[36]

The field test's second objective was to evaluate the effectiveness of the tested procedures in terms of convincing inspectors that actual nuclear weapons were being destroyed. This involved a determination of the ability of inspectors to distinguish between real and fake facilities and weapons and to detect evasion in the analyses of recovered plutonium and uranium. During field operations, inspectors were required to state whether or not they believed the facilities and weapons were credible, whether weapons presented for destruction were real or not, and whether evasion had been practiced during the fissile material analyses. Facilities and analyses were essentially 'innocent until proven guilty', with evasion calls requiring an inspector to support any such accusation with reasons or evidence. Facilities, of course, were genuine so their credibility was never in doubt.

At the lowest access level (A1), less than 50 per cent of calls with regard to the authenticity of weapon shapes were correct. At the highest level (A4), around 80 per cent of these calls were right. There was a significant gap between the number of correct calls at the A1 and A2 levels (48 per cent versus 68 per cent), considerably less so than the intervals between A2, A3 and A4 (68, 75 and 80 per cent respectively). The proportion of correct calls did not vary much with team size or composition but the increase in relation to access level was, as was indeed expected, significant.[37]

Figure 7 Correct calls with regard to weapon authenticity

	ALL WEAPON SHAPES				
Team size	Access				Mean
	A1	A2	A3	A4	
2 man	47%	61%	61%	83%	63%
4 man	50%	75%	89%	78%	73%
Mean	48%	68%	75%	80%	68%
	Low, 58%		High, 78%		

Source: Final Report, page 83.

Of the 96 plutonium assay operations conducted at Rocky Flats, evasion was attempted on 48. LIMA teams detected three of these; MIKE teams detected none. No evidence was gathered to suggest that team size played any part in the successful detections. At Oak Ridge, where recovered uranium was assayed, evasion was practiced on 32 sample operations, none of which were successfully identified.

The third objective was to evaluate the practicability and effectiveness of proposed methods of destruction and to suggest possible improvements. For the most part, methods for demonstrating the destruction of weapons were found to be practicable, with no significant improvements deemed necessary. However, it was noted: 'Technical and operational problems would be reduced considerably if the demonstration were performed in a single facility specially configured for that purpose.'[38]

The final test objective was then to identify any operational, technical, classification, safety and/or security problems to arise during its conduct. 'Many problems arose in all these areas', noted the report, 'but most were minor and to be expected in a one-time field exercise of the nature of FT-34.'[39] Some of the more significant problems, however, included difficulties in maintaining accurate weight records, equipment malfunctions and time and scheduling constraints.

During the special assay exercise undertaken by military inspectors from the LIMA and MIKE groups, just four of 95 evasions were successfully identified. Twelve evasions were practiced as part of the assay exercise undertaken by the three Y-12 scientists; none were detected. Thus, out of a total 187 assay evasions attempted in total across all three exercise portions of the field test, only seven were detected (four in the first special assay exercise; three in the overall destruction test)—a detection rate of four per cent. Seemingly not much, but as the final report saw it, four per cent represents 'a substantial risk for the evader.'[40] (However, it should be noted—as the report does—that most of these detections were the result of equipment malfunctions or mistakes by laboratory personnel.)

That said, the effectiveness of evasion increased as the test progressed, with the result that the team of Y-12 scientists were unable to successfully identify any attempts at evasion. 'There probably would always be some risk, however,' noted the report, 'that even the best prepared evasion schemes would fail and be detected.' More could be done though, on the part of an evader. 'While the risk of inspectors detecting seven out of 187 evasion attempts probably would tend to deter a host from trying to evade, evasion operations tested were relatively unsophisticated when compared to some techniques which could be employed,' it said.[41]

No data collected, though, 'indicated any significant differences in the performance of teams during assay operations due to team composition. Evasions were deliberately designed to be detection-proof and succeeded when modified equipment functioned as planned; those evasions detected did not relate to team composition.'[42]

4.5 Conclusions and recommendations

The first major conclusion drawn from the experience of FT-34 is that for the concept of demonstrated destruction tested, many items of classified weapon design information would be revealed even at the lowest level of intrusion. But it was felt that almost all classified information could be protected in the future through the redesign of facilities and equipment coupled with heavy restrictions on access. Redesign would consist of the construction of a specially prepared facility 'wherein universal tooling and fixtures would be used for weapons and material disassembly.'[43] And with regard to access, as was put in an annex to the Final Report: 'It may be possible to protect most classified information during a demonstration in a specially prepared facility if inspector access is limited to visual inspections of weapons and facilities, if some features of weapons are effectively masked, and if fissionable materials are blended.'[44]

Accordingly, the Final Report noted that if the protection of classified information was to be the highest priority during a demonstrated destruction exercise, special facilities would need to be prepared and access to the demonstration would need to be low and very heavily controlled. Problematically, as the report recognised, such restrictions would only generate a 'very low' level of confidence among inspectors.

And in any case, while it would be theoretically possible to protect most—if not almost all—classified information using the combination of a purpose-built facility and access restrictions, a post-test analysis of the value of all information revealed during the conduct of FT-34 indicated that it was 'unlikely that all information of use to a foreign government could be protected' as some of this information was unclassified and available from only 'superficial visual inspection' of weapons presented for destruction.[45] The Final Report cautioned that prior to any access by inspectors to an area where fissionable material is processed, 'great care must be taken in cleaning those areas so that small samples of material which may reveal classified information cannot be collected,' noting that the gathering of micro-samples by inspectors 'could be inconspicuous to host escorts.'[46]

With regard to conviction, it was concluded that at the low level of intrusion envisioned in the basic test concept, inspectors' abilities to discriminate between real and fake nuclear weapons is poor. 'Results indicated that many calls at this level were mostly guesses.'[47] As was noted in the report: 'Although the ability to detect fake weapons increases with access to weapons being destroyed, inspectors would require *complete access* to the destruction process to be *reasonably certain* that genuine weapons were being destroyed.'[48] Thus, if a high level of conviction in the destruction of nuclear weapons is required, access must be extremely high with inspectors given considerable freedom. Which, of course, directly conflicts with any requirement to protect classified information, and so an acceptable middle-ground, trading openness against limitations on access, would need to be agreed upon prior to the commencement of an actual demonstrated destruction operation involving a foreign inspection team. 'Limitations on access of inspectors should be carefully controlled,' is how the report puts it, 'depending on the degree of protection of classified information desired versus the degree of credibility of the demonstration desired.[49]

In addition, it was found that inspectors can be easily evaded when performing analyses of fissionable materials in host-controlled laboratories. Indeed, the report judged that successful evasion schemes could be designed to make the U-235 content of a sample to appear to be as much as five per cent higher than is actually the case. However: 'Evasions may be detected by alert inspectors . . . if evasion operations or systems do not have a high degree of reliability or if personnel effecting evasions become careless in their operations. Accordingly, a potential evader would run some risk of being detected.'[50] It was noted that inspectors must be allowed complete control over equipment and materials used for the assay of fissionable materials, preferably in their own laboratories, if they are to be assured that results are legitimate.

Also drawn from the study was the conclusion that the amount of classified information and other data collected by inspectors (56 per cent of that exposed) 'seemed to be limited by the capabilities of the inspectors and not by the inspection methods as such.'[51] Inspectors lacked the necessary training and experience to detect all of the classified aspects of nuclear weapon design that were revealed to them. Analysis of the information detected highlighted the fact that team size had little bearing on detection capability but that access was a major factor—especially the use of cameras at higher access levels. Notably, 'more information was detected as teams inspected at higher access levels after having inspected at lower access levels,' indicating that greater exposure and on-the-job learning have a 'considerable effect' on the ability of inspectors to detect classified information.[52] The 'desirability of practice inspections,' in relation to this point, was emphasised.[53]

With regard to problems encountered during the test, it was concluded that weighing errors are 'probable' in an exercise spread out over so many sites and involving a variety of scales and recording systems. Such errors could be reduced, though, by minimising and standardising weighing operations, using accurate scales, and exercising greater care in making calculations and recording weights. Meanwhile, the requirement to operate across four geographically distant sites, while this was judged to have had 'no significant effect on the results of the test',[54] generated 'some inconvenience, confusion, duplication of effort, and added expense.'[55] These negative aspects could have been mitigated had the test been reduced to fewer facilities, said the report, or, even better, completely consolidated at a single, specially prepared, test site.

Looking to the future, the Final Report recommended that before any demonstrated destruction of weapons took place under the gaze of foreign inspectors, a study should be undertaken of the specific weapons to be destroyed. This would allow US officials to determine the types and numbers of weapons to be presented in order to conceal the amount and type of nuclear material in each weapon. It was also recommended that a study be made of how fissionable materials might be mixed to conceal enrichments or impurities that could reveal classified information. Furthermore, no foreign inspectors should be invited into the US to inspect a demonstrated destruction until a 'thorough field test inspection by US inspectors', building on the work of FT-34, has been conducted. 'The primary purpose of such a test would be to assure as much as possible that classified information would be protected by the procedures to be agreed upon.'[56]

5. Taboo-breaking in the 1980s: the Black Sea Experiments

In July 1989, American and Soviet scientists took part in a series of joint experiments, widely known as the 'Black Sea Experiments', to examine the utility of different methods of verifying nuclear weapons at sea. The experiments took place amid US-Soviet differences over the inclusion of long-range nuclear-armed sea-launched cruise missiles (SLCM) in ongoing Strategic Arms Reduction Treaty (START) negotiations. The Soviet Union had a keen interest in applying limitations to this class of weapon system while the United States, which held an advantage in terms of SLCM deployment, argued that limits on nuclear SLCMs could not be adequately verified. In addition, the US Navy objected to any transparency measures that would publicly reveal the presence of warheads on board its ships as they visited foreign ports, given the sensitivity of this issue.

In an effort to demonstrate the feasibility of the verification of nuclear-tipped SLCMs, the Soviet Union invited a group of US scientists to take part in a verification demonstration on board the *Slava,* a Soviet cruiser, in the Black Sea. This joint effort stands out as the first instance in which foreign scientists were allowed to take radiation measurements on an operational nuclear warhead. Another peculiar feature was that the American scientists who participated in the experiments did so in their own personal capacity, without any official affiliation. In fact, according to Thomas Cochran, who led the US team, the US government actively discouraged their participation in the exercise as they didn't want to set a precedent that might encourage a reciprocal Russian visit to a US warship.[57] The five US scientists taking part in the experiments did so under the umbrella of a non-governmental organization called the Natural Resources Defence Council, which partnered with the Soviet Academy of Scientists to run the exercise.

5.1 Access and different warhead measurements

Although the *Slava* had launcher tubes for 16 cruise missiles, in the experiment it was equipped with only one nuclear warhead mated to a medium-range anti-ship cruise missile that served as the focus for all verification activities that were to follow in the exercise. US scientists used their own high resolution detector to record gamma radiation emitted from the warhead. US scientists were allowed direct access to the warhead and a generous timeframe in which to take their measurements. According to Mr Cochran, the detector was placed about 70cm from the centre of the warhead and left to run for around 20 minutes. The warhead was not shielded but the launcher casing was intact and gamma rays had to penetrate through it. The US team was allowed to record the full spectrum of the gamma reading and no measurement information was withheld.

For their part, Soviet scientists carried out their own set of radiation measurements while their US counterparts observed. One such experiment was a direct gamma measurement similar to that taken by the American scientists but using a detector of lower resolution. Soviet scientists also conducted other remote detection experiments. One was from a nearby landing ship using a 0.25 square meter array of sodium iodide counters. Another was using a Soviet helicopter-borne system designed to detect and measure neutron emissions from SLCMs. In this case, as the helicopter flew slowly over the cruiser, the detector was able to detect neutrons produced from the spontaneous fission of plutonium-240 contained as an impurity in the warhead on board the ship.[58]

The helicopter-borne system was supplemented with a laser range finder to measure the distance from the ship, and a video recorder for visual correlation. It relied on an accompanying ship carrying additional equipment that was able to provide detailed data analysis for the target cruiser as a whole, or for any specific area within. Another neutron detector on board that ship was used to detect background neutron emissions that were necessary for the interpretation of findings from the helicopter-mounted neutron detector. The system was designed to detect neutron measurements from a distance up to 100-150m from the neutron source. For demonstration purposes, Sovietnik, the name assigned to the integrated system, was flown on two helicopters past the *Slava* at distances of 30m and 80m.

5.2 Results and conclusions from the experiments

While no comprehensive, publicly-available, official report of the Black Sea Experiments' findings was ever produced, the results of the endeavour were nonetheless reported by individual participants in different outlets, including *Science,* the *Bulletin of the Atomic Scientists* and *Science and Global Security.* The following section of this report uses these sources as the basis for its examination of the experiments.

With regard to the measurements taken by the American scientists on board the *Slava*, the recorded gamma radiation spectrum showed distinctive gamma peaks of the two fissile isotopes of uranium-235 and plutonium-239, thereby confirming their presence. According to the American scientists involved, it also showed gamma rays from the decay of other isotopes (U-232), indicating that the source of uranium used in the warhead was reactor fuel further processed for weapons use.[59] Analysis of the spectrum also provided information on the isotopic composition and uranium enrichment level. The low number of gammas from the decay of uranium-238

(4 per cent) indicated that the isotopic composition of uranium was predominantly of the highly enriched variety. Most analysts agree that no sensitive design information or warhead yield was revealed by the single gamma measurement taken by the US scientists.[60] Mr Cochran suggests that the choice of a single reading was to avoid the disclosure of sensitive design information that could be deduced from a series of readings at different distances.[61] This might include identification of the different stages (i.e. primary and secondary) in the warhead and an estimation of the distance between them.

The tests conducted by Soviet scientists for remote detection produced mixed results. The attempt to remotely detect warhead radio emissions from another ship passing along the cruiser using a 0.25 square meter array of sodium iodide counters did not yield satisfying results. The experiment was referred to by participating American scientists as unsuccessful.[62]

In contrast, results from the helicopter-borne Sovietnik system were more promising, in as much as it was able to confirm the existence of a neutron source on board the *Slava*. To minimize measurement uncertainty, a threshold estimated at a level that exceeds background measurement fluctuations by three standard deviations was established. [63] The reading from the helicopter-mounted detector was compared to that threshold. After processing and comparing the data from Sovietnik system, Soviet scientists declared with a high level of confidence (described as no lower than 95 per cent) that the *Slava* had a neutron source on board that could be remotely detected.[64] Moreover, Russian scientists announced that the system was able to correctly identify the area on the ship housing the source through analysis of data from different zones.

By way of a conclusion, it is fair to say that the Black Sea Experiments broke new ground in a number of ways. Their biggest achievement, though, was in contesting some of the 'red-lines' applying to direct verification of nuclear warheads. The application of radiation detection methods, in the form of gamma ray measurements on a nuclear warhead, was remarkable given the Cold War setting. Indeed, one of the major significances of the Black Sea Experiments was that measurements of nuclear weapons spectra were allowed to be taken by foreign nationals with no attempt made to hide classified properties. The experiments in the Black Sea can thus be considered as representing a significant milestone on the way to establishing transparency and mutual confidence between Soviet and US scientists.

The experiments also demonstrated the limitations of using remote detection methods in warhead verification. Despite the Soviet announcement of the successful detection of a neutron source through using Sovietnik, the system proved unable to provide them with the means to identify any further information on the type or class of the warhead under examination. The contribution of Sovietnik remained constrained by its inability to identify further properties of the neutron source detected, i.e. the system could not tell which class or type of nuclear warhead it was measuring. This underlines the central role that on-site, and perhaps even direct access, inspections have to play in any warhead verification regime.

After the Black Sea Experiments, efforts to verify SLCM limitations stopped abruptly. The United States and the Soviet Union both agreed that SLCMs would remain outside the scope of START and hence the need to design a verification regime for SLCMs was indefinitely deferred. Both states, however, agreed in a joint statement in 1990 to accept a limit of 880 on deployed nuclear-armed SLCMs with ranges exceeding 600km, and to annual declarations on planned SLCM deployments. Despite the US and USSR agreeing in the joint statement to 'seek mutually acceptable and effective methods for SLCM limitations', the Black Sea Experiments had no sequel.[65]

6. Optimism in the 1990s: the DOE Study (1996–1997)

In the autumn of 1996, in anticipation of a future US-Russian accord mandating further reductions in nuclear warheads beyond START I and the ultimately unimplemented START II, the US Department of Energy (DOE) Office of Arms Control and Nonproliferation commissioned a technical study to identify on-site 'Transparency and Verification Options' that could be implemented at DOE facilities—particularly Pantex and Y-12—to monitor warhead dismantlement. Transparency, for the purposes of the study, was a term used in reference to measures providing *confidence* that a declared activity was taking place, while verification referred to measures *confirming* that such activities were actually taking place as declared. [66]

The study, the report of which was released in May 1997, focused on three key questions:

- If a third START treaty was to mandate a time frame for US and Russian warhead dismantlement, how could the rate of dismantlement be monitored?
- Does a warhead dismantlement monitoring regime require the US to enter into an Agreement for Cooperation for the exchange of Restricted Data (RD) and Formerly Restricted Data (FRD)? In other words, how the requirements of transparency and verification can be met within the US system for classification of warhead design information.
- What role can the different US Departments play in the process of verification of warhead dismantlement? In particular, is monitoring at DOE facilities sufficient to confirm the dismantlement of a specific type or class of warhead, or must Department of Defence (DoD) facilities be involved also. That is the impact of when verification regime starts on the ability to confidently verify dismantlement of a particular warhead.

6.1 Monitoring activities

In order to investigate these questions, the DOE established a Dismantlement Study Group comprising of technical experts from its own Office of Arms Control and Nonproliferation, the Office of Defense Programs, the Office of Security Affairs, the Lawrence Livermore National Laboratory, the Los Alamos National Laboratory, the Pacific Northwest National Laboratory, the Sandia National Laboratories, the Pantex plant and

Y-12. After reviewing a number of past studies, this study group identified ten key monitoring activities—general in nature, and therefore equally applicable at both US and Russian facilities—that could be used as part of a warhead dismantlement monitoring regime. They are, as follows:

Declarations: of dismantlement schedules, warheads, and components resulting from the dismantlement process. As the DOE study report noted, declarations—consisting of statements concerning aspects of a host country's nuclear weapons programme—form the basis of any warhead dismantlement regime. While not strictly a monitoring activity but rather a foundation for monitoring, declaratory statements can range from numbers of warheads available to the host, to information about scheduled dismantlement, to information on where and what is kept in storage.

Spot checks: of weapons receipt and storage areas, and of component storage areas, with a view to confirmation of the abovementioned declarations (including the use of radiation signatures of weapons and components). While declarations are a necessary part of any dismantlement monitoring regime, by themselves they are clearly insufficient to confirm dismantlement is actually taking place. Random spot check inspections, employing varying levels of intrusiveness, represent one method of improving the credibility of declarations. Initially, notes the report, spot checks provide only a moderate level of confidence, 'but with continued application, the level of confidence rises considerably as the statistics improve.'[67]

Remote monitoring: of weapons receipt and storage areas, and component storage areas. This refers to the application of various 'containment and surveillance technologies' to provide a level of confidence that events either have or have not (as the case may be) taken place without inspectors present. Cameras—possibly coupled with anti-intrusion image storage units or real-time satellite links—are usually employed to monitor storage areas and perimeters. Tags and seals applied to storage buildings or individual containers to indicate, or indeed discourage, tampering also fall under the heading of remote monitoring. Notably, to be effective in providing credible information, a remote monitoring system would have to be tamper proof.

Chain-of-custody (1) of warheads and components from storage areas to dismantlement facilities. Chain-of-custody is a technique used to provide continuous monitoring of the existence or presence of a treaty accountable item. It 'demonstrates that an unaltered or uninterrupted custody or control of an item has been maintained by the owner or inspector, depending on the monitoring protocol, that provides confidence that deceptions have not been introduced.' In the case of a warhead dismantlement monitoring regime, chain-of-custody would need to begin to observe condemned warheads as early as possible in the dismantlement process—possibly even before the weapon arrives at a DOE facility to be taken apart. As noted by the DOE, the level of intrusiveness that accompanies chain-of-custody depends on the types of measurements that inspectors are allowed to see and do, and the types of records that they are permitted access to. 'The ultimate in chain-of-custody would include having inspectors observe the actual dismantlement, either remotely or directly.'[68]

Chain-of-custody (2) of warheads and components within the dismantlement area.

Chain-of-custody (3) of nuclear components from dismantlement areas to component storage areas after dismantlement.

Portal Perimeter Continuous Monitoring (PPCM): to inspect every item that passes in and out of a segregated portion of a dismantlement area. For PPCM to be effective, inspectors must control all access portals to a facility of interest, either through the use of remote monitoring technologies or actual visual inspection of the facility's entire perimeter. All traffic into and out of the facility is then directed through a single portal, or a small number of them, with inspectors having the right to stop and examine anything passing in either direction large enough to conceivably contain a Treaty Limited Item (TLI). Importantly, PPCM is usually thought of as a system that limits the intrusiveness of monitoring TLIs, particularly with regard to treaties such as START where TLIs are large and only able to be moved around in a heavy trucks or railway cars. However, in a dismantlement treaty scenario, PPCM would need to be extremely intrusive as some TLIs taken from warheads could be far smaller and smuggled over the perimeter with relative ease. For a PPCM strategy to be effective in monitoring dismantlement of warheads, in the view of the DOE study group, inspectors would need to maintain a continuous watch on the perimeter. In addition, PPCM for small TLIs requires a 'very thorough' initialisation procedure to ensure that no items that could be used to mock up items of inspection have been hidden within monitored areas. PPCM can either be classified or unclassified, depending on the measurements that inspectors are allowed to carry out: 'An unclassified, but still highly intrusive, scenario can be constructed in which the inspectors monitor all items large enough to contain a TLI, but using measurements that only reveal the presence of fissile material.'[69]

Sweeping or sanitising: of disassembly bays or dismantlement cells before and after dismantlement has taken place. Sweeping of bays and cells is defined as allowing inspectors to search them before dismantlement to determine that no nuclear warheads or warhead components are already present, and that no undeclared portals exist by which warheads or components could be brought in or out undetected. Inspectors would then examine the declared warhead in a staging bay in order to determine that it is an actual TLI warhead using fingerprint measurements and Tamper Indicating Devices (TIDs). The warhead would then be taken into the bay/cell to be separated into its various components—pit, secondary, high explosive and other assorted non-nuclear parts—while inspectors would remain outside. When nuclear components (pit and secondary) are removed from the cell (in sealed containers) inspectors would perform radiation or fingerprint measurements in the staging area and apply TIDs. The inspectors could then search the cell to make sure that no nuclear components have been left behind. Chain-of-custody techniques could then be applied to verify that all removed components are placed in monitored storage.

Direct observation: of the dismantlement process (e.g. during the disassembly of the nuclear 'physics package' and separation of high explosive and pit). Actual observation, whether carried out directly or remotely, would result in the 'highest confidence' that dismantlement is really taking place. 'Routine use of this activity could be appropriate if a very high level of confidence in dismantlement is required as part of a true verification regime.'[70] But this kind of direct or remote observation could also be performed on a more limited basis, for instance, if inspectors wanted to guarantee that a component came from a specific warhead so that a radiation signature template could be developed, or to resolve an 'ambiguity', as the report put it, in the dismantlement process. In order for actual observation to be carried out, a dismantlement cell would need to be specially prepared to protect information not intended for sharing with inspectors who would then observe proceedings either by going into the cell or via closed circuit television cameras.

Disposition monitoring: of non-nuclear warhead components, such as high explosives and electronics, after dismantlement. Monitoring of non-nuclear components involves the physical and administrative tracking of components as they are removed from warheads and rendered inoperable or destroyed outright, and potentially includes the use of video equipment or direct observation of destruction. In contrast to earlier studies, which concluded that monitoring the destruction of non-nuclear components would have little arms control significance, the DOE study group found that monitoring of such disposition 'can add to the preponderance of evidence that functional nuclear warheads are being dismantled and that a proper disposition process is in place for all major nuclear warhead components.' Indeed, said the report: 'Verified destruction of non-nuclear major components may increase confidence that a particular type of warhead has been dismantled and that a country's ability to regenerate those warheads has been made more difficult.'[71]

After consideration of operations at Pantex and Y-12, and taking into account the 'significant cultural changes' in favour of openness at both plants (and at the DOE) in preceding years, the study group concluded that all of the ten monitoring activities described above could be applied at either the so-called Unclassified to Confidential National Security Information (U to C/NSI) level or the RD/FRD level. They could not be completely unclassified because some activities include monitoring the movement of weapons and components. Under classification guidelines, the report notes, dates and times of movements of weapons and components outside a protected area are classified at the C/NSI level.

6.2 Monitoring options

On the basis of the ten monitoring activities identified by the study group, four options for monitoring warhead dismantlement were considered for discussion, ranging from monitoring only warhead and component storage areas to highly intrusive measures inspecting the actual dismantlement process itself inside the dismantlement area. These options were then evaluated against a set of seven criteria: level of confidence; negotiability (or likely acceptability to the Russians); inadvertent loss of classified information; impact on normal plant operations; amount of preparation needed; cost to prepare and host the initial inspection; and routine cost of hosting each inspection thereafter.

The first option to be discussed against these criteria was the monitoring of warheads and components in storage areas coupled with chain-of-custody monitoring to and from the entrance to the dismantlement facility—but not inside. Also involved would be declarations of the dismantlement schedule and inventories of warheads and components resulting from dismantlement. Spot checks to confirm the accuracy of those declarations would be allowed. Designed to be the most minimally intrusive method, and to have the least impact on normal plant operations, this option would accordingly provide the lowest level of confidence that dismantlement had genuinely taken place of all four considered.

The second option included all of the measures of the first, plus PPCM of a segregated portion of the dismantlement area dedicated to monitored dismantlement (PPCM around the entire perimeter was deemed to be overly intrusive and costly). Following an initially significant impact on plant operations at Pantex caused by the segregating of a specific area (which it was estimated might take up to two years), Option 2 would,

Figure 8 Monitoring options identified by the Department of Energy

Option 1	Monitoring of warheads and components in storage areas coupled with chain-of-custody to and from dismantlement facility, but not inside.
Option 2	All measures under Option1, plus portal perimeter monitoring of a segregated potion of the dismantlement area dedicated to monitored dismantlement.
Option 3	All measures under Option 1, plus further chain-of-custody within a segregated portion of the dismantlement area and to and from the disassembly bays and dismantlement cells—but no portal perimeter monitoring.
Option 4	All measures under Option 3, plus direct observation or remote monitoring of the dismantlement process itself.

the report concluded, provide a moderate to high confidence level that dismantlement was taking/had taken place there, depending on the level of classification chosen, at a relatively low impact on normal operations—both in the segregated portion and the rest of the plant. But in any case, since this option would involve a permanent inspector presence, an idea generally unappealing to the Russian Federation, its negotiability was deemed to be low.

The third option consisted of all of the measures from Option 1 plus further chain-of-custody within a segregated area (but no PPCM of this area) as well as to and from disassembly bays and cells. By removing PPCM, this option aimed to make the fullest use of chain-of-custody procedures. Thus, in addition to declarations and spot checks, Option 3 provides a direct and continuous chain-of-custody from the arrival and storage of a warhead at Pantex (or a secondary at Y-12), to and from dedicated dismantlement bays in the dismantlement area. Under Option 3, inspectors would have the right to sweep and sanitise bays and cells before and after disassembly and the right to examine a warhead or secondary in a staging area before dismantlement gets underway (with inspectors not present). After dismantlement, as the (containerised) nuclear and non-nuclear components leave the bay/cell, inspectors would be permitted to perform further radiation measurements to confirm the absence or presence of fissile material and/or satisfy themselves that the components being removed are actually being taken from the previously presented TLI. The study group noted that it might not be feasible to perform radiation measurements in bays and cells, with feasibility depending upon the size of the equipment involved, the time required to take the necessary measurements and the number of people involved.

The fourth option involved all of the measures permitted under Option 3, plus direct or remote observation of the dismantlement process itself. By being the most intrusive, Option 4 also 'provides the highest confidence in dismantlement of any of the options considered' by the study. Direct observation of the dismantlement process, however, would reveal Restricted Data and, as a result, the study noted that an Agreement for Cooperation would be required, 'assuming that the US and the Russian Federation were willing to exchange such sensitive information with each other.' That said, the study group also declared that remote observation of the dismantlement process using a suitably authenticated video camera 'could, in principle, be done at the unclassified level if classified details are masked.' While such masking might involve the actual covering of classified features, it was felt that information loss could also be controlled by restricting the field of view available to inspectors or limiting the resolution of optical devices. If negotiated—which was thought unlikely due to the level of intrusion—and implemented at Pantex, Option 4 measures were expected to have a high impact on normal plant operations, after a two-year preparatory period of facility modifications.

Figure 9 Monitoring options set against the seven evaluative criteria identified by the DOE

		Confidence in dismantlement	Negotiability	Inadvertent loss of classified information	Impact on operations	Operational readiness		Cost of routine inspections
Option 1	C/NSI	Low	High	Low	Low	1 year	$2.5m	$0.12m
	RD/FRD	Moderate	Low-Moderate	Low-Moderate	Low	1 year	$2.5m	$0.12m
Option 2	C/NSI	Moderate	Low	Low-Moderate	Moderate	2 years	$12.0m	N/A
	RD/FRD	High	Low	Moderate	Moderate	2 years	$12.0m	N/A
Option 3	C/NSI	Moderate	Moderate	Moderate	Moderate	1.5 years	$6.5m	$0.2m
	RD/FRD	Moderate-High	Low-Moderate	Moderate-High	Moderate	1.5 years	$6.5m	$0.2m
Option 4	C/NSI	Moderate	Low	High	High	2 years	$6.5m	$0.2m
	RD/FRD	High	Low	High	High	2 years	$6.5m	$0.2m

* Note that Option 2 assumes a permanent presence of inspectors—hence N/A in final column—at a cost of $5.5m per year.
Source: Transparency and Verification Options, page 14.

6.3 Conclusions

The study group's first major conclusion was that any treaty involving the monitoring of nuclear warheads, warhead dismantlement and fissile material stockpiles would have a significant impact on the DOE's nuclear weapons complex. Consequently, careful planning would be needed to ensure that a future START III treaty mandating dismantlement would not affect the DOE's ability (and responsibility) to maintain a safe, secure and reliable stockpile of US nuclear weapons. In order to minimise both the disclosure of sensitive information and the impact on normal plant operations, it was judged that 'there may be some *significant advantages in using a dedicated dismantlement facility*' (emphasis added).[72]

Next, assuming an item arriving at Pantex for dismantlement really is a nuclear warhead, it was concluded that warhead dismantlement transparency or verification can be achieved by implementing the monitoring activities identified by the study group. Transparency could also be achieved through a combination of the monitoring activities with up to a moderate level of confidence that dismantlement has taken place without the need for an Agreement for Cooperation to exchange classified information, though since verification of dismantlement would require the exchange of RD or FRD that would probably require such an agreement to be in place.

Assumptions aside, the study group found that determining whether an item to be dismantled is a genuine warhead is in fact very difficult and may require both chain-of-custody procedures from DoD facilities (such as from a deployment or weapons storage site) to the dismantlement facility and the use of warhead radiation signatures to correlate the signature of a particular warhead with those of its components post-dismantlement. Furthermore, it was found that a distinction between strategic and tactical warheads, or between warheads of different types, can only be made *before* the warhead arrives in DOE custody—meaning that if a treaty was to require distinctions of these kinds to be made, a chain-of-custody regime would likely need to be initiated at the point at which the warhead is removed from a delivery vehicle, deployment site or DoD weapons storage depot.

It was additionally concluded that were a treaty to require a specific quantity of warheads to be dismantled, the rate of dismantlement and the number of warheads dismantled could be monitored using all four of the options investigated, because the accumulated data from declarations, spot checks and confirmatory measurements would be sufficient to allow for such determinations to be made. (However, under Option 1, the rate and number of dismantled warheads can only be determined if warhead radiation signature methods successfully correlate warheads going into the closed-off dismantlement area with components coming out.) It was felt that confidence in the quantity of warheads dismantled would increase as the number of inspections per year increased and be highest when (or more likely if) a permanent inspector presence was allowed.

Further to its conclusions, the DOE study made several major recommendations—and a number of subsidiary ones—for future action.

First, since a determination of warhead category/type can only be made in conjunction with information obtained outside of a DOE facility, an analysis of warhead monitoring procedures that could potentially be implemented at DoD facilities—flagged but not considered by the DOE in this report—should be undertaken. Second, a study should be conducted to identify and evaluate options for warhead dismantlement monitoring that could be implemented in Russian facilities, taking into account the 'significant asymmetries' between the US and Russian nuclear weapons complexes, especially the fact that Russia has at least four dismantlement facilities whereas the US only has one (Pantex). Third, a more in-depth quantitative analysis of all four options studied, including costs for each, was recommended. And fourth, the study group recommended that in-depth analyses be conducted in the following areas: advantages and disadvantages of warhead radiation signature methods; security and vulnerability issues associated with taking radiation measurements of nuclear warheads and/or components; options that could be implemented at DOE facilities to promote the 'irreversibility' of nuclear weapon reductions (as called for by Presidents Clinton and Yeltsin); and, last but by no means least, the construction and use of a dedicated dismantlement facility designed with transparency and verification in mind.

The last point is perhaps the most crucial of all, and stemmed from the clear understanding that, from a monitoring perspective, the setup at Pantex was (or is) far from ideal. Bays and cells, for instance, are not concentrated in any one location but are rather scattered across the site, with dismantlement activities sharing space with activities of other kinds. It would, the DOE's report noted, 'greatly facilitate' any monitoring process if dismantlement facilities were to be isolated from non-dismantlement ones. Moreover, for safety reasons, bays and cells at Pantex have only limited personnel access. In cells, the limits are eight operators and eight observers; in bays the limits are six and four respectively. Excess space that could be used for monitoring purposes in bays, cells and connecting passages is scarce. In addition, according to the report, retired US warheads are not dismantled one after another, which in turn leads to several warheads in various stages of disassembly and dismantlement residing in bays and cells at any one time. Clearly, such a situation gives rise to significant monitoring complications—tags, seals and radiation signature measurements would all need to be employed, at a minimum, by foreign inspectors to track the movement of individual warheads as they move along the dismantlement chain.

7. Intergovernmental Involvement: the Trilateral Initiative (1996–2002)

The Trilateral Initiative—a joint venture involving the US, Russia and the IAEA—was launched in September 1996 by the IAEA's then director-general, Hans Blix, to investigate the technical, legal and financial issues associated with IAEA verification of classified forms of weapons-origin and other fissile material deemed surplus to defence requirements. The aim of the Initiative was to establish a system of verification under which states in possession of nuclear weapons might submit excess fissile material to IAEA monitoring as a guarantee against its reuse in, or diversion to, weapons.

The Initiative was eventually concluded in 2002, after a series of nearly 200 meetings. For each of the project's six years, activities under it were guided, reviewed and approved by a US-Russian ministerial meeting, with the two countries' representatives on the IAEA Board of Governors liaising with the head of the Agency's safeguards department on the sidelines of each meeting of the Board. Documents produced were done so 'in confidence', with distribution strictly limited to the parties involved. To this day, precious little information on the Initiative has been released into the public domain. And much of what has emerged has been related to the technical side of the Initiative, which included work in three areas: authentication; inventory monitoring systems; and the verification of the conversion of classified fissile material to unclassified forms.

Writing in 2001, Thomas Shea—who served as head of the IAEA Trilateral Initiative Office for its six-year duration—explained that an essential underlying principle of the Initiative was the understanding that any decision to submit material to verification by the Agency, once made, would be irrevocable. A state would retain full decision-making power over what material to submit, but would not then be able to reverse its decision. 'Moreover,' wrote Mr Shea, 'in keeping with the need for verification, once the decision [was taken] to submit certain materials to the IAEA, inspections would be obligatory.'[73]

7.1 Rationale for the Initiative – why IAEA safeguards were inadequate

In the context of their NPT Article VI (disarmament) obligations, the US and Russia decided to develop a new monitoring and legal regime addressing, in a dedicated and irreversible manner, their weapons-origin fissile material deemed in excess of military needs. Previously, such material was subjected to voluntary offer safeguards agreements with the IAEA.[74] But by the mid-1990s, a continued reliance on voluntary offer agreements was viewed as an unsatisfactory arrangement—for a number of reasons. First, if not foremost, the IAEA's normal safeguards system is designed to prevent the diversion of nuclear material and/or facilities from peaceful to non-peaceful uses in non-nuclear-weapon states; it is not set up to address nuclear material and facilities associated with weapons programmes.[75]

In addition, the placing of material under voluntary offer agreements with the Agency did not represent a permanent solution as the material could theoretically be withdrawn from monitoring at any time. Furthermore, existing agreements employed traditional IAEA verification techniques, which—in the otherwise necessary spirit of transparency—could obviously not be applied to classified weapons material without revealing proliferation-sensitive information of the kind prohibited by Article I of the NPT. A fourth problem was that IAEA safeguards under voluntary agreements are implemented only when sufficient resources are available, which is not often. [76]

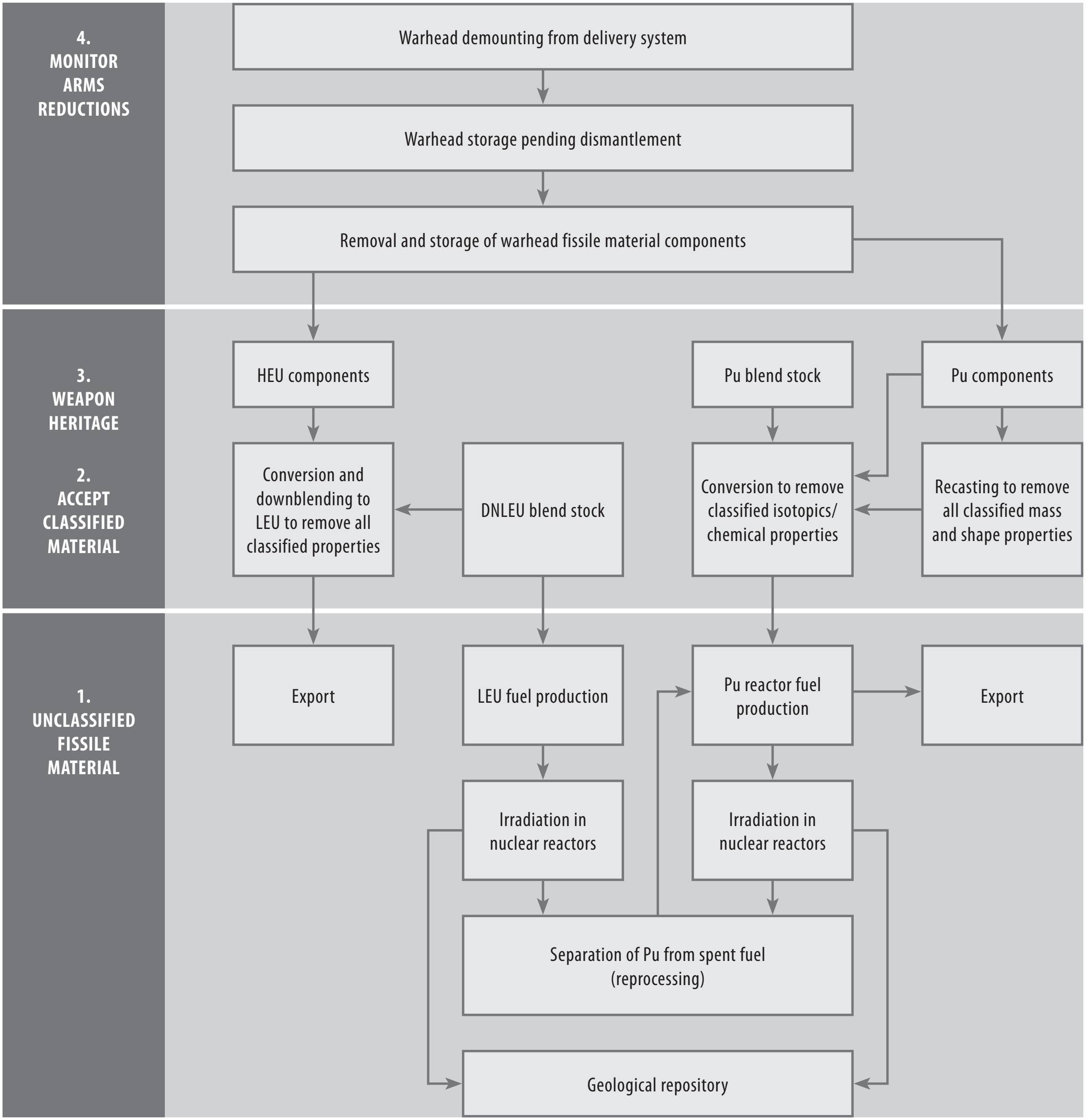
As Mr Shea has noted, the Trilateral Initiative 'sought to broaden the items that could be brought under IAEA monitoring to include any classified items containing plutonium or highly enriched uranium, including nuclear warheads, warhead components, pits, or secondaries.' And it sought to ensure that these would be permanently safeguarded, without breaching strict Article I obligations against the sharing of sensitive weapons-related information. Since this obligation—which in the NPT is couched in terms of weapon and non-weapon states—logically extends over multilateral entities such as the IAEA also, the Agency recognised that its access to the US and Russian nuclear weapon complexes would be necessarily restricted in order to maintain an acceptable level of nuclear secrecy.[77]

7.2 Progress under the Initiative

Following the Initiative's launch, the three parties established a Joint Working Group to consider the issues involved.[78] Early discussions centred on the nature and scope of the envisaged verification system, with a balance needing to be found between political/legal acceptability and credibility. One critically important decision related to the nature of the nuclear material that countries would submit for verification.

Four verification levels were considered. Level one was to limit the Initiative to fissile material processed to the point at which it no longer contained any classified properties that could reveal weapons secrets. Level two was to accept classified forms of fissile material without attempting to establish that the forms actually represented nuclear warheads or warhead components. Level three would have seen the Initiative include verification provisions to confirm that the properties of items presented were characteristic of nuclear warheads, or components thereof, including specific model identifications, while level four would have begun verification at the point of separation of warheads from their delivery systems. The working group decided that the

Figure 10 Flow chart showing levels of verification considered as part of the Trilateral Initiative



Source: presentation by trilateral intiative member, AWE, 2008.

Initiative should aim for the level two, a level of not inconsiderable difficulty but considered to be achievable nonetheless. Level one was not viewed as radical enough (in addition to the fact that it would have involved significant delays—and significant costs—while classified material was converted to unclassified forms), while levels three and four were seen to present unpalatably high security and proliferation risks.[79]

With the level of verification set, attention turned to even more technical matters, namely, the means by which verification would be accomplished.

7.2.1 Development of the information barrier

Initial studies suggested that no measurements could be done on weapons-useable plutonium—no particular work was being done on uranium, despite the fact that weapons-origin fissile material refers to this as well—without revealing some sort of classified information. Therefore, the Initiative had to develop a device that would allow nuclear-weapon states to invite IAEA inspectors to take readings of nuclear weapon components without gaining access to sensitive information. For its part, the IAEA would need to be sufficiently assured of the credibility and independence of the verification procedure. Every possible measurement method was considered, beginning with those already in use by the IAEA to safeguard plutonium and highly enriched uranium in non-nuclear-weapon NPT parties. What this review concluded, however, was that all methods could reveal weapon secrets if inspectors were allowed access to the raw measurement data. As a result, direct, quantitative measurements following normal IAEA safeguards practices were ruled out.[80]

Consequently, it was agreed that verification of the fissile materials in question would need to employ technology designed to block quantitative measurements from view and provide IAEA inspectors with binary 'pass/fail' readings only—a so-called 'information barrier' that would keep verification activities within the bounds of Article I.[81]

Information barriers can be based on two different concepts. Either they can use template verification, based on a stored signature of a particular type of warhead, or they can be based on the verification of agreed attributes. The Trilateral Initiative opted for the latter approach. To do this, plutonium attributes first had to be defined somehow, and eventually the Initiative settled on three variables that would need to be detected and confirmed:

- That plutonium is present;
- That the metal has an isotopic composition such that the ratio of plutonium-240 to plutonium 239 is 0.1 or less; and
- That the metal's mass is above an agreed minimum defined in relation to each facility.

Agreement on these attributes meant that the Initiative could start work on designing a device that would allow inspectors to address warhead authentication issues without revealing the sensitive properties of an item under observation.

'Pass/fail' determinations would be made by comparing the actual (hidden) measurement data with a set of pre-agreed unclassified reference points, or 'attributes', enabling IAEA inspectors to make measurements on the components of nuclear weapons without being exposed to design secrets. For example, the presence of a militarily significant quantity of weapons-grade plutonium would be determined by measures that first checked for the presence of plutonium, then assessed that the isotopic composition of the plutonium was weapons-not reactor-grade before finally calculating that the plutonium mass fell above a mutually-agreed minimum threshold. The Joint Working Group identified several methods that could be used to satisfy these requirements, eventually settling on high-resolution gamma ray spectroscopy to establish the presence of weapons-grade plutonium and its isotopic composition, and a combination of this technique with neutron multiplicity counting to measure plutonium mass. Although 'attribute verification with information barriers' would provide the IAEA with far less information than obtained under normal safeguards, it was judged sufficient to be formally accepted as the basis for Agency verification of the classified materials involved in this project. Indeed, Trilateral Initiative experts went on to develop and demonstrate a prototype information barrier system.[82]

7.2.2 Other technical research areas

In addition to work on attribute verification systems, work also proceeded on inventory monitoring systems for facilities designed to store weapon-origin fissile material: systems combining traditional safeguards containment and surveillance measures that would track material within such facilities and be able to assure its identity, integrity and location at all times.[83]

Consideration was also given to the steps required for the verified conversion of fissile material from classified to unclassified forms and its subsequent disposition. IAEA monitoring would, in these instances, begin with the arrival of classified material at the entry point of a conversion facility, with a perimeter monitoring system ensuring that only containers under chain-of-custody procedures—plus any other non-weapon materials needed—would be allowed in. All fissile material containers leaving the conversion facility would then be measured using normal IAEA safeguards procedures, after which seals would be applied to the containers prior to their storage or transport to fuel processing facilities. Managed access would be allowed into the conversion facility on an annual basis to ensure that no warhead components had accumulated within and that no undeclared penetrations had occurred. IAEA inspectors would be allowed to watch containers entering the measuring system, identify tag measurements, confirm seals and observe pass/fail attribute measurements. The Joint Working

Group felt that if such a scheme was to work successfully, conversion facilities in which IAEA verification took place would need to be based on standard architectural plans. However, no further discussion of such plans took place. [84]

The Working Group initially felt that the ideal solution to the chain-of-custody problem would be to have unattended monitoring of all items en-route to storage. However, they could only reach agreement on how to verify the stored inventory according to a sampling plan. Here, they had to make an assumption on what constituted a 'strategic change' in the inventory. The outcome became known as the 'one per-cent solution'. A break-out involving on the order of one per cent of the monitored inventory could portend a strategic change. This solution was never formally adopted, but served as the de-facto reference for determining the subsequent sample plan.

7.3 The end of the Initiative

In September 2002, Mohammed ElBaradei, then IAEA director-general, told the Agency's general conference that 'preparatory work' under the Trilateral Initiative had been 'largely concluded,' and that experts from all three parties had agreed 'that the technical solutions developed under [the] Initiative could allow the Agency to verify any form of fissile material without disclosing sensitive information.' Preliminary estimates of verification costs had been made, said Mr ElBaradei, and a legal framework for verification developed.[85] By this time, both the Bush and Putin administrations had decided that the Initiative should be brought to a close.[86]

There were a number of reasons why the Initiative was not brought into force. For one, the United States wanted Russia to submit roughly the same amount of plutonium in roughly the same forms as the US. But while the US wanted to put entire pits under verification, the Russians wanted to melt their pits into two-kilogram balls. Since the US had no intention of converting its pits in this way, the two sides were out of sync. While technical activities still continued, the IAEA found itself increasingly having to maintain the pace of the activities.

Another sticking point was a lack of authorization. Russia's IAEA Governor at the time, Ambassador Mikhail Ryzhov, attempted to gain Moscow's approval to engage in negotiations of a Trilateral Initiative Agreement with the IAEA. In this, though, he was unsuccessful. With new administrations in the US and Russia at this time, both holding different agendas and priorities than their predecessors, interest in the Initiative waned and momentum driving the process declined significantly. In addition, the signing of the Plutonium Management and Disposition Agreement between the US and Russia in 2000 had the effect, in Mr Shea's words, of 'draining some of the necessary political impetus and attention' from the Trilateral programme.[87]

Several important questions remained unanswered at the time the Initiative was brought to a close, both on the technical and political fronts. The first related to the question of *equipment authentication.* How can the inspector be sure that the equipment he or she is using has not been tampered with beforehand? Two possible options were proposed by the Working Group:

- The IAEA produces the system, which is then reviewed by the states. One problem with this approach, however, was that any such review might take as long as 18 months.
- The states produce the system in multiple copies. The IAEA then takes a sample away for review, while it places the remaining systems under seal. This was deemed to be the most workable solution of the two.

The other question related to compliance: what happens if an anomaly is detected? What would the status of the remaining items be, and how could the anomaly be resolved?

The US/Russian press release announcing the conclusion of the Trilateral Initiative directed the technical experts to begin discussions on future cooperation under the trilateral format without delay. But this was never to happen. There was a lukewarm attempt to revive the technical work in September 2003–but ultimately it came to nothing. The comprehensive 2002 report to the Trilateral Initiative Principals, detailing technical, legal and financial issues, remains 'in confidence'. As do the four annexes to the report, including the technical documentation. Nonetheless, as an important addition to the state of knowledge, the last word on the Trilateral Initiative is perhaps best left to the neat closing summary of its own Joint Working Group:

> 'Over the course of six years, the Joint Working Group addressed the technical, legal and financial issues associated with implementing IAEA verification of weapon-origin and other fissile material released from defence programmes and can now recommend the successful completion of the original task. The enabling technologies developed under the Initiative could be employed by the IAEA on any form of plutonium in nuclear facilities, without revealing nuclear weapons information. The Working Group found no technical problem that would prevent the IAEA from undertaking a verification mission in relation to such fissile materials released from defense programmes, and believes that many of the technical approaches could have broader applicability to other forms of fissile materials encountered in conjunction with nuclear arms reductions.'[88]

8. Studies in the United Kingdom (1998–2005)

In 1998, Britain's Strategic Defence Review (SDR), the main defence planning and policy document of the United Kingdom, made a point of noting that the effectiveness of arms control agreements 'depends heavily on verification.' The UK, it remarked, has a 'particular expertise in the monitoring of fissile materials and nuclear tests,' and it was Britain's intention to build on this knowledge 'by developing capabilities which could be used to verify reductions in nuclear weapons, drawing on the expertise of the Atomic Weapons Establishment [AWE] at Aldermaston.' Accordingly, the SDR announced the commissioning of an 18-month study 'to identify the technologies, skills and techniques required and what is available in [the UK].'[89]

That study produced an unclassified report for general circulation, entitled *Confidence, Security and Verification: The challenge of global nuclear weapons arms control.* This was released by AWE in April 2000.[90] Its findings were presented at the sixth Review Conference of parties to the Nuclear Non-Proliferation Treaty (NPT) the following month, where the UK also announced the initiation of an on-going research programme, aimed at addressing the technological aspects of nuclear arms control verification. This programme was designed, in the words of an interim report issued three years later, 'to consider technologies that could be used in the verification of any future arrangement seeking to reduce and ultimately eliminate stockpiles of nuclear weapons.'[91]

Britain had identified what it saw as a gap—or perhaps a gaping hole—in the field of nuclear verification. While verification of the absence of nuclear testing was addressed by mechanisms established to monitor the Comprehensive Nuclear-Test-Ban Treaty, and verification of the absence of nuclear weapon activities in non-nuclear-weapon NPT parties was a matter for the IAEA and its safeguards, a UK working paper submitted to the 2000 conference noted the lack of any 'multilateral or international verification arrangements covering the reduction, elimination and dismantlement of nuclear weapons and the ultimate disposition of the fissile material they contain.' The development of 'effective verification capabilities and arrangements in this area' was, said the paper, 'critical to sustaining systemic progress towards achieving reductions of nuclear weapons and their eventual elimination.' Verification of nuclear reductions and elimination was, it further noted, an area in which 'all States have an interest in the development of further national and international capabilities as an essential contribution to the process of nuclear disarmament.'[92]

Such was the rationale behind the launch of the UK's verification research programme. Two interim progress reports were submitted to meetings of the NPT Review Conference's Preparatory Committee in 2003 and 2004 respectively, and a further, consolidated report was presented at the NPT Review Conference in 2005. At this event, the UK invited approaches from other interested state parties to discuss possible co-operative research in the field.

Early on, the UK research programme identified four key areas relevant to the verification of nuclear arms control in a future possible treaty situation:

- Authentication of nuclear warheads and their components (i.e., establishing that an item declared to be a nuclear warhead or a warhead component is consistent with those declarations);
- Dismantlement of warheads and their components;
- Disposition of the fissile material resulting from dismantlement to ensure that it can no longer be used in nuclear weapons or other nuclear explosive devices;
- Monitoring of nuclear weapons facilities and complexes.[93]

During the course of the programme it was decided that the issue of disposition was sufficiently well-covered by established safeguards regimes, and that the study would therefore focus primarily on the remaining three: authentication, dismantlement and nuclear weapons complexes.[94]

8.1 Authentication

In the words of *Confidence Security and Verification*: 'Authentication of warhead and warhead components is at the centre of the global nuclear weapons arms control verification challenge.'[95] Subsequently, from 2000 until the publication of the UK's first interim report in 2003, much of the work of the British verification research programme was focused on warhead and component authentication, as this was deemed to 'almost certainly be the most technically challenging verification task arising from any potential arrangements to control nuclear warheads directly.'[96] The AWE also took advantage of dismantlement operations being carried out on warhead types retired from service. With only one operational warhead system, investigating the dismantlement of previous designs allowed the UK to examine the impact of warhead design diversity on the practical challenges associated with authentication.

A UK finding early on was that one of the most important technical approaches to authentication would involve identification of the characteristic radiation 'signatures' associated with nuclear warheads. Radiation monitoring falls into two basic categories of Non-Destructive Assay (NDA) techniques: passive and active.[97] Passive NDA methods rely on the fact that all nuclear warheads contain fissile isotopes of plutonium or uranium that emit either neutron or gamma radiation. Some of this radiation will escape from the warhead and be 'passively' detectable outside of it. In this way, valuable information can be obtained and deductions made regarding the type, distribution and quantity of the radioactive materials contained within. Active NDA techniques, on the other hand, use external sources of radiation to cause particle emissions. Example include neutron induced fission in the fissile materials such as highly enriched uranium and x-ray induced photo-neutron emission in warhead materials containing low atomic number elements—deuterium, tritium and beryllium for instance—that do not give off characteristic signatures that are easily measured passively. For example, the 2003 UK report explained: if examined sequentially by x-ray of three different peak energies, 'these neutrons can then be detected externally to the warhead using simple detectors and . . . can be used to indicate the presence of some specific elements and hence to increase confidence that the object under consideration is a nuclear warhead.' The AWE work recognised that these techniques could also reveal sensitive and/or proliferative design information, which presents an additional authentication challenge.

During the first three years of the UK's research programme, radiation signatures from a number of British nuclear warheads—including both those being decommissioned (namely, the WE177 free-fall bomb/nuclear depth charge and the Chevaline warhead) and the in-service Trident—were examined using a mixture of both passive and active techniques. A variety of approaches were adopted for passive radiation signature measurements of warheads and components; including low and high resolution gamma-ray spectrometry and time-correlated neutron assay. Additionally, experiments used an active technique to examine the feasibility of X-radiation to determine the presence of elements with low atomic numbers in warheads or their components. This experimental work was supplemented with computer modelling and calculations. [98]

It is important to note that the UK measurement of radiation signatures, on their own warheads and components, was carried out in a classified environment and that no such access to direct measurement could be countenanced except within such a protected boundary, by fully security-cleared personnel. So the following conclusions would not apply directly to any realistic situation in a future hypothetical treaty situation involving a foreign treaty partner. From its work on authentication, the UK drew seven principal conclusions:[99]

- Fissile material in a number of different types of nuclear warheads or warhead components can be detected externally using relatively simple instrumentation;
- Detection of a nuclear warhead can be made in a number of locations (such as in storage and various other containers), although;
- In many instances detection would require close access to an item, often within a few metres.
- The number of warheads inside a container can be assessed, while;

- In some cases, fissile material mass and some geometrical dispositions of nuclear materials is able to be estimated using high resolution spectroscopic techniques;
- It may be possible to 'reverse engineer' design information from this kind of raw radiometric data according to the UK's work—meaning that great care would need to be exercised in using technical transparency technology in any dismantlement verification agreement; and
- X-ray interrogation of components was judged to be a technique that could be used to verify non-fissile strategic materials often found in nuclear warheads, but on this point the UK's working paper stated that further investigation was required. The practical challenges of fielding the equipment for measurements of type within a production environment had not been considered in any depth.

More generally, it was noted that in developing authentication technologies, the issue of "intrusiveness" was paramount and that proliferation risks and states' national security concerns must be considered alongside and be integrated within all verification technology development. In this connection, the concept of the "information barrier" developed in the US in the 1980s, and brought to prominence through the Trilateral Initiative, was relevant.

8.2 Dismantlement

The UK's report to the following Preparatory Committee meeting in 2004 focused on work undertaken on verifying a future possible dismantlement of warheads and their components under a hypothetical future treaty. As the 2004 paper noted, the 'key requirement' of dismantlement verification is to provide confidence that all outputs from the dismantlement process come from items previously authenticated as nuclear weapons. That is to say, that no deception has been introduced into the process along the way. 'Crucial to achieving this', said the paper, 'are likely to be various techniques for establishing continuous knowledge of the items during the process (a chain-of-custody) and some acceptable combination of non-visual and visual means of inspecting these items at various stages during the overall process.'[100]

Ensuring a chain-of-custody while an item is being moved through the various stages of dismantlement requires the application of 'appropriate technological means to maintain control over the stated condition of the warhead, its components and sub-components' in order to ensure no diversion takes place. Britain's 2004 research paper highlighted four methods of achieving this: tags and seals, remote monitoring (closed-circuit television, for example), item tracking (i.e. following an item's passage through a facility using handwritten or bar-coded record cards) and/or portal monitoring (aimed at ensuring that no materials can be removed from facilities without proper authorization). It was noted, however, that the 'vulnerability to tampering' exhibited by this quartet of techniques was an area of major concern.[101]

On inspections, dismantlement verification using both non-visual and visual access means were considered. Techniques that do not necessarily require direct visual access and which, for security reasons, may need to be shielded (e.g. by an 'information barrier') include, for one, the sampling and analysis of warhead materials—not necessarily just fissile materials but structural and other inert materials also. (For some materials, an inspector might be able to estimate the age since manufacture which, when compared to the declared age of the warhead, can aid confidence in the overall verification process.) For another, there is the potential for comparison of warhead NDA signatures—using gamma-ray spectra and radiographic methods, for instance—with known 'templates' of specific warheads.[102]

A further non-visual technique would be that of environmental monitoring. During the disassembly of a nuclear warhead, there are various ways in which characteristic gaseous or particulate emissions (if there are any) might be detected from a weapons facility— by chemical or radiometric means for example. During dismantlement of Britain's Chevaline warhead, air-sampling measurements were taken within the facility and smears taken from containers and the warheads themselves. Materials identified from these samples were consistent with materials known to be used in the warhead undergoing dismantlement.[103] As the paper pointed out, the detection of these materials 'could give some confidence to the declaration that a nuclear warhead is being disassembled.'[104]

A full summary of inspection techniques that do not necessarily require direct or visual access is given in Figure 11 below:

Figure 11 Summary table of inspection techniques not necessarily requiring direct or visual inspector access

Technique	Comment
Tags and seals	Requires access by inspector to containers but not necessarily to the component
Remote monitoring	No direct access required but there is a need to ensure that sensitive information is not transmitted
Item tracking	Could require direct access by an inspector
Portal monitoring	No direct access required
Sampling and analysis of materials	Some form of access required but sampling could be done by hosts under inspector supervision
Radiation signature comparison	Some form of access required although information barriers could be employed
Mass balance	Probably no direct access required to verify records but some access may be required to verify the material concerned
Paper and computer records	No direct access required but information contained could be classified

Source: UK NPT working paper, 2004, page 12.

Inherently and unavoidably, direct visual inspections will be more intrusive in requiring inspectors to gain close access to a warhead and its sensitive inner workings. 'It would therefore be necessary', cautions the UK's paper, 'to consider very carefully whether it is possible to accept the resulting risks, which may involve compromising sensitive information, in order to provide inspectors with more confidence that the dismantlement process has occurred.' To complicate matters further, no two inspection protocols would be the same: 'A risk/benefit analysis will need to be undertaken for each individual case, given that a generic solution for every scenario is unlikely.'[105]

In May 2002, the UK conducted a managed access 'mock inspection' in the AWE's assembly/disassembly area—a highly secure area in which warheads and their components are handled and where visual access stood to reveal sensitive warhead design information—in order to explore the feasibility of conducting an inspection of high-security facilities by non-security-cleared, foreign inspectors. Although the mock inspection in question was judged to have had 'considerable operational impact and security implications', the UK adopted the position that 'wherever possible, inspections of this type should be accommodated.' Indeed, one of the principal conclusions of the 2004 paper was that managed inspector access to sensitive nuclear warhead facilities, done properly, is able to permit some degree of access for non-security cleared personnel. Nonetheless, it was recognised that determining and managing the degree of access that could be granted to foreign inspectors without compromising sensitive information was an area that would require further consideration.[106]

8.3 Weapons complexes

The results of the UK's research on the monitoring of nuclear weapons complexes was presented to the NPT Review Conference in April 2005, along with the consolidated findings of the research programme to that date.

While recognizing the lack of an agreed definition of a nuclear weapons complex, for investigative purposes it was defined as being:

- A site where one or more scientific or industrial activity required to produce/disassemble a nuclear warhead is carried out; plus,
- Any other location where an unsafeguarded activity is carried out (and where the primary function is to serve the production, storage or disassembly of a nuclear warhead/device).

(Note: this excludes nuclear fuel cycle activities that can be addressed through conventional safeguards arrangements.)[107]

Nuclear weapons complexes will, of course, vary from country to country—in terms of size, geographical distribution and complexity. And this variety, noted the UK's 2005 paper, 'will need to be taken into account for any future potential verification regime.' Certain characteristics, however, are common to all nuclear weapons complexes, including production technology used and environmental emissions produced (whether solid, liquid, gas or particulate in form). Environmental measurements can be useful in assisting the verification process.

With regard to nuclear weapons complexes, the goal of verification would be 'to provide independent confirmation of, *inter alia,* the size and disposition of the declared warhead stockpile, the production/dismantlement rate of warheads and precursor components, plus inventories and movements of fissile material.'[108] Potentially assisting in the accomplishment of this goal could be the installation of verification systems inside facilities (facility monitoring) or monitoring of the interfaces between facilities and the outside world (e.g. power usage, staff movements, environmental emissions) in order to determine whether they are operational and complying with declared activities. 'The choice of system', noted the UK, 'would depend upon the degree of intrusiveness, as well as issues such as reliability, accuracy and cost, that could be tolerated. . .It is recognised that the techniques of greatest value will be those that are flexible, as facilities differ from one state party to another and potentially have multiple uses.'[109]

Facility monitoring—designed 'to ensure that no clandestine material enters a warhead production cycle,'[110] as the AWE put it in 2000—can be done in a number of ways, either using technologies that are intrusive (such as sampling within ductwork, taking smears for radio-chemical analysis or taking direct radiometric and other measurements from facility waste) or non-intrusive (such as off-site air sampling). These techniques can then be supplemented by technologies such as the use of radioactivity-detecting portals on access roads and remote monitoring.[111]

As part of the UK's verification research, existing measurements of emissions from the UK's nuclear weapons complex—taken for regulatory monitoring purposes—were also studied for their verification applicability. It was subsequently concluded that whereas the techniques used in taking these measurements were 'appropriate for ensuring regulatory compliance, in order for them to meet the more stringent requirements for verification, increased sensitivity would be required as well as an enhanced ability to detect specific isotopes and chemical species.'[112]

Another aspect of the UK's work in this area was the examination of potential new techniques that could be used to differentiate between emissions from recent nuclear weapons complex operations and legacy material from past operations, a matter of verification interest 'because of the possibility of false alarms when determining whether operations have occurred that are outside the operative dates within an agreed treaty.' For instance, high-resolution satellite imagery[113] might be used, as indeed could hyperspectral imaging,[114] indications of plant stress,[115] airborne gamma spectroscopy readings[116] and the monitoring of resources and consumables.[117]

8.4 Summary of conclusions

The UK's extensive investigation into the verification of nuclear disarmament reached a number of strong conclusions by the time of the NPT Review Conference in 2005, including the need for greater research into verification technologies and the importance of finding an appropriate balance between transparency and security.

Authentication of warheads and their components—looking back to 2003—was judged by the UK researchers to represent the most technically challenging verification task, since, as was stated in 2005, 'a strong element of any technique or technology chosen or developed to address it would need to fulfil the need to also protect national security and proliferation-sensitive information; and to overcome any inadvertent or deliberate generation of false indications.' Testing of a range of technologies on UK warheads and their fissile components led to the conclusion that 'many aspects of the authentication process are achievable but, in many instances, close access to an item is required and in some cases sensitive nuclear weapon design information may be vulnerable.'[118]

Subsequent work on warhead dismantlement verification included consideration of various techniques that could be applied as part of the disassembly process, including chain-of-custody (e.g. tags and seals, remote monitoring, item tracking, portal monitoring) and inspection techniques (e.g. NDA analysis and environmental monitoring). 'A significant conclusion from this work', said the UK in 2005, 'was that managed access could facilitate some form of access for non-security cleared personnel into sensitive nuclear warhead facilities,' but that there was a further need to determine the degree of access that could be given to inspectors 'without compromising defence- and proliferation-sensitive information.'

Then, in 2005, the UK concluded that the monitoring of nuclear weapons complexes would 'need to consider established facility and environmental monitoring and to supplement this with a range of additional remote monitoring techniques.' In addition to which, UK research indicated that the goal of verification vis-à-vis weapons complexes 'is more likely to be achievable if the monitoring is reinforced by procedures, such as routine and challenge inspections deploying a range of technologies.'[119]

9. The UK-Norway Initiative

Collaboration between the UK and Norway into the verification of warhead dismantlement began against a backdrop of deep divisions between nuclear and non-nuclear-weapon states at the 2005 NPT Review Conference. Those divisions ultimately led to the failure of the conference to adopt a final outcome document and a wide realization that the gap between nuclear and non-nuclear-weapon states needed to be bridged if the NPT regime was to remain viable.

The UK came to the conference on the back of a unilateral multi-year research programme, undertaken by the AWE, into verification technologies applicable to the dismantlement of nuclear warheads. The UK had presented interim reports on their research to the 2005 Review Conference's 2003 and 2004 Preparatory Committee meetings, and a consolidated report of findings to the 2005 Review Conference itself. At that conference, the UK expressed an interest in exploring opportunities for cooperation with other states in the field of nuclear arms control verification.

In Norway, a country that has traditionally played a proactive role in multilateral disarmament fora, they found a willing partner. In 2006, Norway established a study group on disarmament and non-proliferation consisting of arms control and non-proliferation experts from several Norwegian research institutions. The purpose of the group was to explore the technical basis for disarmament and non-proliferation by engaging experts from nuclear-weapon states and non-nuclear-weapons ones as well as from the IAEA. A key objective was to identify areas where researchers from both groups of countries could cooperate to further the goal of nuclear disarmament and non-proliferation.

Against this backdrop, both countries decided to set in motion a dialogue on verification issues involved in multilateral nuclear disarmament. As part of this, both countries began a peer review exercise with the Norwegian study group undertaking to critically examine the work the UK had unilaterally undertaken in relation to nuclear warhead dismantlement verification over the preceding years.

9.1 Peer review

The peer review led to the publication of two discussion papers: one on non-nuclear-weapon state perspectives on the use of information barriers in disarmament verification and the other reviewing the UK's working paper series on disarmament verification (see previous chapter).[120] Norwegian institutions taking part in the peer review felt that there remained several areas where further work or improvements were necessary.

With regard to its conclusions on information barriers, the first discussion paper noted that while this technology had been the subject of 'intensive study' in the past, notably as part of the Trilateral Initiative, 'comparatively little' had been published on it. Discussion of information barriers 'has been largely restricted to government scientists in NWS,' said the paper. From the outset, the peer group recognised that many, 'if not all of the questions [relating to information barrier technology] have doubtless been discussed before and possible answers formulated, particularly by scientists in nuclear weapons states.' But not widely discussed or shared with those on the non-nuclear-weapons side. 'Thus, even if information barrier technology were "fit for purpose" NNWS might lack trust in the results of verification systems that used it.' As a result, the group concluded, it is 'extremely important to involve NNWS in the development of information barrier technology at an early stage.'

The peer group identified two possible evasion scenarios that an information barrier would need to be able to detect. First, a nuclear-weapon state could attempt to cheat an inspecting party by removing fissile material from a warhead before the authentication process began. An 'incomplete' warhead such as this is said to have a defect. Alternatively, a nuclear-weapon state could attempt to cheat by substituting a real warhead for an object designed to mimic its properties—by using materials that emit neutrons and gamma rays with an appropriate spectrum, for instance. Such a device is said to be a spoof warhead. A spoof warhead might well comprise an incomplete real warhead, with the addition of extra components to disguise the existence of a defect.

In addition, the discussion paper raised a number of pertinent questions, among them: 'what size of defect must the authentication process be able to detect?' And how can information relevant to authentication but obtained from other sources (e.g. by ensuring continuity of knowledge) be used in the verification process? Moreover: 'Can a necessary degree of assurance be provided without recourse to "high tech" information barrier systems?' Given the fact that NWS have tended to insist that they must be able to manufacture any authentication equipment to be used on their warheads, the study group went on to suggest that the UK and Norway investigate what scope existed for NNWS to be involved in the manufacturing process.

The second paper, on the UK's working paper series, noted that the three documents jointly represented a 'valuable and timely set of ideas and thoughts into nuclear disarmament verification, covering several aspects relevant to the topic.' But while acknowledging the 'explorative nature' of the working papers, the paper suggested that 'somewhat tighter structuring' would have been desirable. 'The set of working papers may appear somewhat fragmented and in part driven by a technological opportunism,' the peer group contended, 'rather than a comprehensive, open-ended analysis.' Lack of vision appeared as a criticism: 'At times, the studies seem to ask what kind of verification methods and technologies are readily at hand, rather than asking pertinent research questions aimed at identifying what kinds of technologies are needed' to meet verification goals.

Furthermore, while it was noted that studies on nuclear disarmament tend to focus on technological fixes, 'the human factor should not be underestimated,' it said, 'both with regard to negative impacts (e.g. faulty or non-qualified use of measurement technology, lack of motivation for or overall understanding of the goal and aims of the activities'), as well as positive spin-offs (e.g. building of relationships, trust and mutual understanding).' These, it was felt, had been dealt with only in passing. 'The UK working papers only discuss personnel issues in connection with elaborations on security risks and clearances,' it said. 'There is evidently scope for further research into this area, which would also give the study a multidisciplinary flavour.'

In terms of technology, though, the Norwegian peer-review paper argued that the likelihood of an item of arms-control technology being accepted increases if the following are considered:

- Measurements cannot reveal classified information;
- Simple technology is preferable to complex technology;
- Familiar technology is preferable to unfamiliar technology; and
- Passive measurements generally are preferable to active interrogation measurements.[121]

All measures put in place should be as transparent as possible, said the peer group—hence the call for simplicity and familiarity. And full reverse engineering of any equipment should also be accommodated, if so desired.

In sum, the UK working paper series highlighted many of the difficulties involved in the verification of nuclear warhead reductions, the peer group noted. But as much as the UK achieved, much remained to be done 'in order to establish practical verification schemes and system designs.' On this point: 'Follow-up work and further studies seem highly pertinent—both of an in-depth as well as of a broad-based manner.'

9.2 The start of the Initiative

Based on the Norwegian study group's review, representatives from four Norwegian laboratories—the Institute for Energy Technology (IFE), the Norwegian Defence Research Establishment (FFI), the Norwegian Radiation Protection Agency (NRPA) and the Norwegian Seismic Array (NORSAR)—met in early 2007 with the UK Ministry of Defence, the Atomic Weapons Establishment (AWE) and VERTIC to discuss potential cooperation on matters relating to the technical verification of nuclear arms control.

Figure 12 Participating institutes

Institute for Energy Technology (IFE), Norway
Norwegian Defence Research Establishment (FFI), Norway
Norwegian Radiation Protection Agency (NRPA), Norway
Norwegian Seismic Array (NORSAR), Norway
Ministry of Defence, UK
Atomic Weapons Establishment (AWE), UK
VERTIC, UK-based

The Norwegian participants were particularly interested in looking at how a non-nuclear-weapon state such as Norway could play a constructive role in building confidence in the process of multilateral nuclear disarmament. The UK and Norway agreed that an unclassified exchange investigating this issue was both achievable and desirable.

Between them, the two countries agreed to initiate a programme of work focusing on two main areas of research: information barrier technology and on-site inspection methodologies. VERTIC was to participate in the role of independent observer. The principal rationale for the project was to investigate ways in which Norway, a non-nuclear-weapon state, and the UK, a nuclear-weapon state, could cooperate on issues relating to the verification of nuclear disarmament without the risk of spreading proliferative information. It was designed to provide an opportunity to consider what level of cooperation might be achievable between a NWS and a NNWS, what issues and complexities might hinder flexibility on the part of a nuclear-weapon state, what level of confidence a non-nuclear-weapon state could have in the verification process, and what technologies and procedures would work in the real world. The Initiative was ultimately envisaged as a way of promoting understanding between nuclear and non-nuclear-weapon states with regard to the views and concerns of the other party, and to encourage discussion as to how NNWS and NWS could jointly contribute to nuclear arms control verification processes.

Under the project, the information barrier and managed access research strands complemented one another. By focusing on these two, the Initiative addressed what are considered to be key features of any future dismantlement verification regime. As will be developed below, the project envisaged both strands merging in the practical setting of an exercise, with inspectors under managed access conditions utilizing information barrier systems developed by the Initiative to verify the dismantlement a mock nuclear warhead.

9.3 The information barrier project

As noted above, the UK-Norway Initiative comprised of two overlapping research strands: information barrier technology and managed access methodologies.

The information barrier technology strand investigated how to develop a system by which an inspector could confirm the presence or absence of a warhead without direct access to warhead measurements. By doing that, the Initiative sought to address what is widely referred as the authentication of warhead/initialization problem. Authentication is considered one of the biggest challenges of any future verification regime. It refers to the ability of inspectors to be sure that an item presented for verification at the start of the dismantlement process is indeed what it has been declared to be. In other words, assurance that a presented item is in fact a genuine nuclear warhead and not a mock or dummy device.

As discussed elsewhere in this report, an information barrier refers to a device that takes readings of classified material, compares that information against a set of pre-agreed 'attributes' and provides inspectors with a simple 'pass/fail' output. Prior to the UK-Norway Initiative, information barrier technology was most notably developed under the six-year Trilateral Initiative between the US, Russia and the IAEA from 1996-2002. Various national verification programmes have also explored the concept.

Using an information barrier, 'uncleared' personnel can in theory take measurements of classified nuclear weapons or weapon parts without being exposed to sensitive design information. Not that any nuclear-weapon state would wish to expose warhead design information, but if inspection personnel were to come from a non-nuclear-weapon state, access to such information would additionally breach NPT prohibitions on the sharing or transfer of proliferative information. Protecting sensitive information in such a context is thus doubly important.

On the basis of a joint design, the UK and Norway built two prototype barriers, one in the UK (by the AWE) and one in Norway (by the IFE and FFI). Designing an information barrier with the involvement of a non-nuclear-weapon state requires a special consideration of factors related to proliferation concerns and confidence. On the one hand, an information barrier designed to work within a dismantlement verification regime that includes a NNWS as well as a NWS would need to adequately address strict NPT non-proliferation obligations. On the other hand, the NNWS party would need to establish sufficient confidence that the information barrier provides accurate readings/measurements, which would entail a direct involvement of the NNWS in all processes relating to the design, manufacture and the certification of the information barrier.

With these factors in mind, the UKNI information barrier designs were developed as 'proof of concept' devices, built to explore the various issues associated with incorporating the above factors. The intention was less to develop a working information barrier designed for use on an actual warhead but rather to test the ability of a NWS and a NNWS to productively cooperate in the design and the manufacture of a system that could be adapted to real world uses. On this point, the barrier prototypes were designed to detect a cobalt-60 isotope, not real weapons-grade fissile material, that was to be implanted inside a mock weapon constructed for the purposes of the Initiative.

The system developed under the Initiative followed some of the main principles guiding the information barrier developed under the Trilateral Initiative. In that regard, it consisted of a radiation detector and an electronic unit. The electronic unit recorded gamma-radiation energy and ran that information through specially designed software to determine whether the recorded energy corresponds to a declared type of radioactive material. The outcome was either a green light for a pass or a red light for a fail. No other information was made available to inspectors and all information was deleted immediately after a result was presented. However, in contrast to the Trilateral Initiative, the information barrier designed by the UK and Norway did not go beyond the ability to measure fissile material presence.

Other features of the UK-Norway Initiative's information barrier included an extensive reliance on simple, off-the-shelf components and the avoidance of unnecessarily complex computation. For example, the electronic unit was built from standard, commercially available parts and designed to be easy to inspect for any unauthorised changes. Furthermore, the design was such that prior to use, a host party could easily substitute any modular components at inspectors' request. Inspectors could then check these components for any alterations. Even after use, all modules except for the data processing module could be available for further inspection. The idea was for the device to be simple, relatively low-cost, lightweight and battery powered such that it could be easily used in the field.

9.4 The managed access project

Alongside information barrier development, the managed access strand proceeded to explore the human factors involved in dismantlement verification, namely, the presence of foreign inspectors in sensitive nuclear weapons complexes. The Initiative assumed that inspectors are likely to require access to highly sensitive facilities at warhead disassembly sites, which would obviously call for forward planning on the part of a host party in order to prevent the unintentional or unauthorized release of sensitive information with proliferative or security value. Managed access thus quickly took on a prominent role in the Initiative, consuming considerable planning time and resources.

This second research strand involved the staging of a number of exercises designed to develop and test inspection methodologies related to nuclear warhead dismantlement. Essentially, managed access is the process by which inspectors are given access to sensitive facilities, or supervised areas, under the terms of an agreed procedure or protocol. Managed access can thus be considered a modified version of a widely-practiced verification technique: the on-site inspection. What is special about managed access, however, is that access under managed conditions is carefully controlled to suit the specific limitations associated with the verification of highly sensitive activities.

The managed access strand stemmed from the recognition that the verification of warhead dismantlement would likely require some sort of on-site inspector presence in order to adequately assure outsiders that warhead dismantling—of real warheads—has in fact taken place. For the purposes of verifying dismantlement, national technical means (i.e. satellite monitoring) are inadequate to provide such assurances; thus, inspectors on the ground are crucial. A series of exercises were designed in order to determine the level of on-site inspector intrusiveness required and the different access modalities that could be applied in real nuclear weapons facilities on real warheads.

These exercises were meant to replicate different stages of an envisioned inspection regime involving a nuclear and a non-nuclear-weapon state, with the latter verifying the dismantlement of a single nuclear warhead retired from the notional arsenal of the former. Exercises were not to be about 'winning' or 'losing'. Rather, they would be held to allow participants and planners to try out different ideas and to see what worked, what didn't, and why. Lessons would be learned from both successes and failures. In contrast to the 1996-97 study of dismantlement by the US Department of Energy (see chapter 7 of this report), this joint British-Norwegian effort was thus to be a fully 'played out' exercise scenario rather than a theoretical examination of various verification options.

Specifically, two inspection visits were held: a 'familiarization visit' in December 2008 and a 'monitoring visit' June 2009. These visits were prepared and overseen by a joint British-Norwegian planning team established in order to supervise the operational aspects of the Initiative. For exercise purposes, the UK-Norway planning team developed a verification scenario to allow the Initiative to assess the various requirements of nuclear and non-nuclear-weapon states in relation to the dismantlement process. Great effort had to be invested into making the scenario 'proliferation-proof' as well as believable.

To increase believability, the planning team first created a realistic, but fictional, framework as a backdrop against which inspection visits would be set. Realism is always critical. Though only an approximation of reality, any exercise designed to investigate and test the feasibility of dismantlement verification has to mirror actual settings and procedures to the fullest extent possible. While perhaps a somewhat obvious observation, but a vitally important one, the more realistic an exercise is, the more important its findings, and the greater its overall value, will be.

9.5 Exercise scenario

The central element of the framework created by the planning team was a notional treaty, the 'Portland Pact', between the 'Kingdom of Torland', a fictional nuclear-weapon state, and the 'Republic of Luvania', a fictional non-nuclear-weapon state. The pact itself was never drawn up, but in a declaration pursuant to it, Torland stated its intention to dismantle its ten 'Odin' class gravity bombs under the supervision of Luvanian inspectors. As played, however, the inspection exercises only dealt with the dismantlement of one mock Odin weapon. The dismantlement was to be deemed complete once the Odin pit was removed from the weapon and placed in monitored storage.

The Portland Pact represented both the foundation for all that was to come after, and—more importantly—the rationale for the drafting of a procedure for verification describing monitoring provisions and the broad outlines of later inspections. The verification procedure was intended to serve as a guide as to what each party had committed to do—commitments that were then to be put into action through negotiations and monitoring. It also set out the basic rights and privileges of both sides, the conduct expected of them, and the overall scope of inspection activities.

The verification procedure included provisions for two kinds of inspector visits: one for familiarization and negotiation purposes (the familiarization visit) and one to monitor the weapons dismantlement process as it took place (the monitoring visit). Significantly, the verification procedure also introduced the concept of confidence-building measures (CBMs), 'composed of additional activities by the host party in support of its declaration and at its discretion,' to the exercise. Notwithstanding the fact that this was assumed to represent a cooperative endeavour, not a challenge inspection, the value added by CBMs was to encourage the host party to take additional measures when and where appropriate with a view to building additional trust.

In the interests of realism, the planning team strove to build as much context around their notional treaty and verification procedure as they could. Country back-stories were created encompassing historical and political information, resources and economic capabilities, and security interests/issues of concern. To add even greater depth of context, planners augmented all this information with other relevant information, including a description of Torland's entire supposed arsenal of nuclear weapons and a timeline of its nuclear history (tests and so forth) to date. Also produced was a range of fictional open source information that both player teams had access to before exercises began.

The process that inspectors were asked to verify involved the monitoring of a mock warhead through its various dismantlement stages according to a dismantlement flow designed by exercise planners. During the exercise, the warhead and its components were kept in containers at all times other than when disassembly operations—out of sight of inspectors—were taking place. The flow covered the movement of a nuclear weapon and its components from the weapon's entry into the dismantlement chain at a pre-dismantlement storage site, through removal of the nuclear physics package from the actual bomb casing, to separation of the weapons fissile pit from its high explosive charges, and to final waste disposition and long-term fissile material storage. Disposition was not covered by the exercise.

During the planning stages, several steps were taken to minimise the risk of any transfer of sensitive and/or proliferative information between the UK and Norway. For one, it was decided that the British and Norwegian participants should switch sides, with the UK becoming the non-nuclear-weapon state of Luvania and Norway becoming the hosting party of Torland. Which also allowed those involved to explore and appreciate the issues involved from an unfamiliar point of view. In addition, it was decided that exercises would be played out in Norway (at a real Norwegian nuclear site 'dressed up' for exercises purposes) and, as noted above, a cobalt-60 isotope was used in place of actual nuclear weapons material.

Under the scenario and context outlined above, inspectors were looking to establish confidence that (a) dismantlement had taken place, and (b) that the item dismantled was really an Odin class weapon as declared. In order to arrive at these conclusions, a two-stage strategy was followed involving a 'familiarization visit' and a subsequent 'monitoring visit', explained in more detail below. Unlike the United States' unilateral exercise undertakings in the 1960s (see chapter on FT-34), no evasion was practiced as part of the UK-Norway Initiative.

9.5.1 Familiarization visit

The dual purpose of the familiarization visit was, first, for inspectors to become acquainted with the locations and procedures that were to be used during dismantlement, and second, for them to reach a negotiated agreement on verification measures (including, *inter alia,* diagnostic measurements, record viewing, tags and seals) that would be employed during later monitoring.

The visiting inspection team (of UK personnel) needed to come away from the familiarization visit with a satisfactory chain-of-custody plan and a sound understanding of the dismantlement process from start to finish. Contingencies that could affect the custodial chain, such as the container holding the physics package needing to be hurriedly put into storage in the event of a fire alarm—which could, of course, be a real intervening factor—also had to be addressed. For its part, Norway, as the host, needed to balance the need to protect information that it deemed sensitive or proliferative against the need to not be seen as impeding an ostensibly cooperative process of verification.

To become familiar with layouts, inspectors were taken on a tour of the facilities that they would later monitor. Tours presented a critical opportunity for inspectors to assess their verification needs, including their sealing and tagging requirements, the number of inspectors they wanted and their positioning at different locations—as well as the points at which they could most usefully deploy measuring devices (including the information barrier).

Access requests during negotiations were then made on the basis of what inspectors had seen and their need to further understand the workings of the dismantlement process in relation to the weapon to be disassembled and the treaty accountable item—the Odin pit—contained within. Matters such as whether inspectors were permitted to seal off rooms (or even whole buildings), who would place seals (and who would break them), where measurements could be taken, what parts of the dismantlement process inspectors would be allowed to witness and so on all had to be decided.

It was left to the hosts to decide what and how many details of their notional weapons complex and dismantlement flow they were willing to share with inspectors prior to the commencement, and at each and all subsequent stages, of negotiations and correspondence. Inspector requests for access to location X, or to station a team member at Y, or to take photographs of Z were considered and evaluated by the hosting team which had to decide whether to accept or refuse them, taking into account the balance between security and openness noted above. The object was not so much to protect the most critical aspects of the dismantlement chain—information that Norwegian players would not know—but rather to protect *what they deemed most worthy of protecting.*

A request for information barrier measurements to be taken on the weapon outside of any container was one request denied to the inspection team by the Norwegian players. UK participants noted that this would be a matter taken on a case-by-case basis but that refusal would probably be a realistic host response given proliferation concerns. Luvania argued that it would have strengthened the chain-of-custody that the measurement was taken on the Odin bomb and not on some other item placed within the container. Torland suspected that the request was a ploy on the part of the inspecting party, who did in fact admit that the request was partly motivated by a desire to have more time to look at the weapon's shape and outer casing.

As part of its negotiating strategy, Torland was keen to frame accommodations reached as 'agreements in principle', always remaining acutely aware of the multitude of potential disagreements that could surface later. By doing so, Torland equipped itself with ready-made escape clauses were differences to subsequently arise. Health and safety considerations also dictated some host responses to inspector requests. Indeed, it was recognised that a cynical host may even seek to manipulate health and safety as a means of limiting inspector access to sensitive areas. Inspectors were also aware of the possibility of their hosts giving ground on small issues in order to deflect attention away from other, more significant ones. Host cooperation—or the appearance of it—was further recognised as one way in which to minimise the amount of time that inspectors spend at host facilities, and so a way in which to minimise the inevitable disruption to normal plant activities that their presence will cause.

As a counter to resistance from Torland, during the familiarization visit, the Luvanian team opted to exert negotiating pressure on Torland from the outset, emphasising early on in proceedings that Luvania would only settle for a verification plan that would stand up to international scrutiny and reminding their hosts that the success or failure of the whole endeavour hinged on the degree of cooperation that Torland was prepared to extend. Participants playing the part of Luvanian personnel felt strongly that the reputation of Luvania would suffer badly if it was later revealed that they had been duped (as would the reputation of any state misled in such a fashion).

Interestingly, by the time of the later monitoring visit, British participants felt that the relative balance of power between inspectors and hosts—which leant slightly toward the former, the invited guests, at the familiarization stage—had been reversed. During the familiarization visit, the onus was on Torland to show cooperation. During the monitoring visit, however, the spotlight seemed to shine more on the inspectors' ability to deliver a robust verification plan as agreed.

The dynamic between inspectors and hosts will form part of any future dismantlement verification regime. Inspectors and hosts have competing priorities, but in a cooperative inspection framework (which the UK-Norway Initiative was intended to represent) both share a joint interest in the success of the verification regime and in demonstrating compliance. While an inspection team will understandably try to gain as much access and glean as much information as they can, their hosts will be expected to guard classified and sensitive information. The complexities and nuances of this dynamic can potentially compromise the success of any verification regime and, in so doing, significantly diminish confidence in it.

By the conclusion of the familiarization visit, both teams had reached a common understanding of the processes involved in the dismantlement of the warhead to be verified. In verifying that process they also agreed on the specific verification requirements, including agreement in principle on the level of access to sensitive facilities and the containerised warhead.

Under that agreement, inspectors were to be allowed to apply various methods to maintain a chain-of-custody of the warhead through the dismantlement process. For the purposes of this exercise, chain-of-custody began with entry of the warhead into the dismantlement facility and ended with the placement of the extracted pit in monitored storage. Inspectors also insisted on maintaining that chain-of-custody whenever the warhead and its components were moved within or between facilities—times at which maintaining custody is particularly challenging.

Transport aside, particular consideration was given in negotiations to those other parts of the dismantlement process at which inspectors were likely to be physically separated from the items they were there to watch over—such as during the removal of the physics package from the bomb casing and during subsequent disassembly of the physics package itself. These stages of dismantlement are among the most sensitive of all, and as a result, verification activities will have to do without direct inspector access to them, which obviously presents opportunities for evasion and, as a result, complicates monitoring matters further.

To increase trust, both sides agreed that all information provided by either hosts or inspectors should be made available to the other party for certification prior to its use, and in good time, so as to allow all equipment to be mutually accepted as fit and appropriate for purpose. In addition, it was agreed that a secure inspector station would be allocated to inspectors for their private use during monitoring activities. Within this space, inspectors would be able to work unhindered by host staff and keep items securely stored.

For inspection activities, inspectors were required to abide by rules and procedures set by the hosting party. Such measures enabled the host to establish a level of control over proceedings taking place in their sensitive facilities. For example, the whole team was informed that if any one inspector failed to surrender 'contraband' items, the inspection visit would be cancelled. Inspectors were also informed that if any of their number were to leave the monitoring visit for any reason, that inspector would not be able to rejoin his teammates on that part of the visit. In addition, regulations covered issues as specific as the rules according to which inspectors could take notes during the course of their duties. This included the use of numbered notepads and pens provided by the host and the checking of inspectors' notes for sensitive information before their release was approved.

Once familiarization visit talks were completed, negotiating outcomes were then formalised in a draft 'Framework Monitoring Agreement' that was to be notionally approved by the governments of both sides. To facilitate the drafting process, a working group formed of selected members from the two parties was created as a means of accelerating matters over a process in which all participants were involved. Once written, the document was then circulated to all members not involved in the actual drafting for comments.

In analysing the conduct and outcome of the familiarization visit it is important to note a number of salient points. First, it is safe to assume that in negotiating a monitoring framework, an inspection team would be likely to insist on the systematic inclusion of redundant measures to support primary verification at all stages of dismantlement. During exercise negotiations, inspectors were determined to have two lines of defence at all points. That way, if one line was to fail—either accidentally or deliberately—then the back-up could be used to investigate and recover the situation.

Second, for its part, a host is likely to adopt and follow a strategy that involves keeping a tight hold over the information it releases to inspectors. In the exercise, the hosts followed a strategy of multi-layered information filtering, providing inspectors with as few details of their nuclear activities as they could, and mainly acquiescing to requests only where national security- or proliferation-relevant information were not at stake.

Third, in planning a monitoring visit, consideration of the wide array of equipment to be used is likely to represent an area for negotiations that cannot be ignored. Both host and inspectors will have to reach agreement not only on the exact specifications of equipment but also on measures by which both parties can ensure that equipment is genuine and accurate. Authentication of inspection equipment is necessary to avoid situations in which a piece of equipment is used for purposes that go beyond its stated role in the regime. In the exercise, authentication of inspector equipment was played only notionally due to the difficulties involved—which in itself serves to illustrate the complexity of this issue.

Fourth, the process of negotiating a verification plan is likely to be influenced by a consideration of the effect that plan would have on normal plant operations in facilities that are to be inspected. Hosts will wish to ensure that at both familiarization and monitoring stages, inspectors are present for the shortest amount of time possible in order to minimise the inevitable disruption that their presence will cause. Although this was not a major issue during the exercise, which followed a strict timeframe designed by the planning team, it was nonetheless borne in mind as a factor that would weigh heavily on the planning of a real-life inspection.

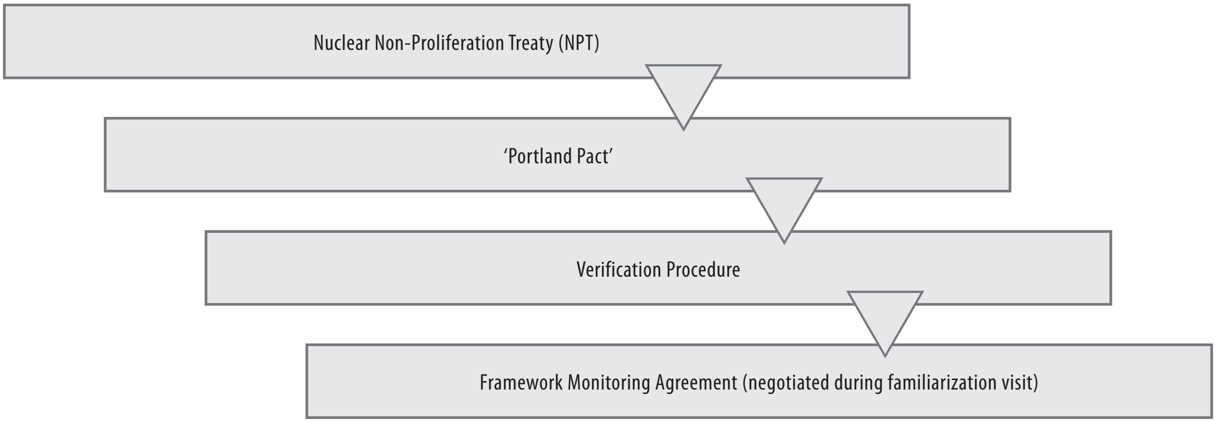
Fifth, it should be stressed that agreement on a verification plan does not—and did not—end with the in-game drafting of the text. Some issues may be overlooked, or may need later review to iron out details and ambiguities that only come to be fully appreciated during post-exercise, out-of-game reflection. Indeed, a lack of sufficient detail in several areas of the document agreed at the familiarization visit resulted in the need for an out-of-game planning meeting to be held afterwards to review and amend the text. Rather than exercise organisers assuming full control over the post-exercise review process, however, in the future it would worth considering the establishment of a formal (in-game) follow-up mechanism—a second familiarization/negotiation visit, perhaps—to allow both teams to fine-tune details, address outstanding issues and exchange remarks ahead of the actual monitoring visit itself. Organisers need to be aware of the danger of allowing the negotiating process to become overly drawn-out, at some point the monitoring itself has to go ahead, but if players are to fully 'buy-in' to an exercise then any key intermediate meetings ought to be played in-game.

In part, it was the short timescale between the familiarization visit held in December 2008 and the monitoring visit scheduled for June 2009 that resulted in the need for a planner-driven review meeting. There was insufficient time to play an intermediate negotiating phase and, therefore, the UK players were asked to specify missing information and planners injected a reply to their requests in the form of a set of workshop minutes. Communication between planners and players with regard to these notional minutes was poor, however. Consequently, players did not fully appreciate their significance until play began. Many UK players admitted to not having read the document and some of those on the Norwegian side pointed out that it was difficult to absorb a document that they had not been involved in producing. It was noted, however, that in reality the familiarization/negotiation stage would be more protracted. UK players felt that a second pre-monitoring visit would have been useful.

9.5.2 Monitoring visit

Essentially, the monitoring visit presented the opportunity for inspectors to assess the host's compliance with its declared intention to dismantle some of its nuclear warheads. At the monitoring visit, the verification plan agreed at the familiarization stage was put into operation.

Figure 13 Legal architecture for the monitoring visit held under the UK-Norway Initiative



Legend for 'legal architecture' flow chart:

- NPT: An international pact that calls on state parties 'to pursue negotiations in good faith on effective measures relating to cessation of the nuclear arms race at an early date and to nuclear disarmament, and on a treaty on general and complete disarmament under strict and effective international control.'
- Portland Pact: A notional bilateral disarmament legal instrument between a NWS and a NNWS within the context of Article VI of the NPT
- Verification Procedure: A notional agreed framework enabling the negotiation, development and implementation of a dismantlement inspection regime.
- Framework Monitoring Agreement: A text negotiated during the familiarization visit incorporating a brief description of the dismantlement process to be verified and those monitoring activities inspectors were to follow.

Following what was agreed in the familiarization visit (and subsequently), inspectors tracked the movement of a containerised warhead and its disassembled components from the moment at which the complete warhead entered the dismantlement facility to the moment at which the fissile pit was placed into monitored storage. In doing that, they used a range of verification techniques including tags and seals, photography, closed-circuit television recording, radiation monitoring and the use of the information barrier technology discussed earlier. In addition, inspectors also reviewed warhead-relevant documentation released (with redactions) by the host.

In applying those verification techniques, the original agreement provided for the host to carry out all measurements under inspector supervision. Such an agreement guarantees that inspectors will not be able to take any measurements of the facility, or of containers, that were not previously agreed to. The various verification techniques used by inspectors are briefly explored below.

Portal perimeter control

Portal perimeter control involves the establishment and maintenance of a contained area with inspectors controlling and checking all items entering or leaving. This technique proved particularly useful during the monitoring visit in verifying activities taking place in areas where inspectors were denied direct access. For instance, during the physical separation of the physics package from the warhead's outer casing and the further disassembly of the physics package to separate its main components (i.e. fissile pit and high explosive charges).

To establish a robust perimeter control, inspectors first had to sweep designated areas where such activities were take place to ensure that those areas were radiologically 'clean' before the introduction of the weapon or any of its parts. Radiation sweeping was done using host-supplied hand-held gamma and neutron count monitors. To make control easier, entry and exit points were reduced to the bare minimum necessary for dismantlement operations. Immediately after sweeping was completed, inspector control of the perimeter, and in particular its entry and exit points, began. Inspectors then swept all personnel, equipment and containers crossing that perimeter, in either direction, to make sure that no traffic in and out carried unauthorised materials. The only exceptions to this rule were sealed containers declared to contain the Odin weapon or its pit. Sweeping was again undertaken once dismantlement had been completed, to ensure that no treaty-relevant materials had been left behind.

Given restrictions on direct inspector access to warhead dismantlement activities, portal perimeter control is sure to assume a prominent role in the maintenance of chain-of-custody while sensitive disassembly activities are taking place. A well thought through methodology that would systematically address the various simultaneous operations involved in maintaining a chain-of-custody needs to be developed and refined if dismantlement processes are to effectively verified in the real world. This might include certain best-practice protocols that would inform and ensure that perimeter sealing was undertaken by inspectors in the optimum manner possible.

Tags and seals

Verification of a complex process such as warhead dismantlement requires deploying effective methods to keep track and maintain the integrity of contained items and areas. Tags and seals play a vital role in fulfilling those functions. They are used to identify containers holding verification-relevant items, to ensure that areas and/or items have not been interfered with when inspectors are elsewhere, and to ensure that no verification-relevant materials have been removed from a facility during dismantlement without proper authorisation.

All tags and seals applied for verification purposes will have to be checked to determine that they have not been removed or tampered with. This involves using one or more of a variety of techniques, such as visual confirmation and/or digital comparison of photographs taken of tags and seals.

During the exercise, simple, commercially available tags and seals were used, with inspectors applying their own unique identifying features on the basis of the so-called random particulate identification technique (RPIT). In checking the seals, photographs of them were taken by inspectors and then verified using simple computer software.

In general, the tags and seal types that were used functioned well enough over the short timescale of the monitoring visit. For longer periods, though, more sophisticated and robust tags and seals would likely be needed to provide credible assurance of integrity. Vehicles were found to be particularly difficult to properly seal. That, coupled with the time-consuming nature of seal deployment and evaluation, points toward the possible need for future investigation of the use of Tamper Indicating Enclosures (TIEs), which would allow inspectors to create 'verifiable spaces' within enclosed boundaries. TIE concepts could include boxes enclosing equipment, overpacks around containers and workspaces within controlled boundaries. It is a key area for further research.

Closed-circuit television cameras (CCTV)

CCTV is used for remote surveillance purposes. In a verification context, they provide visual confirmation that no personnel or equipment has entered or left a facility while inspectors were not physically present. CCTV was used in the exercise, although only notionally, at various points where information within the field of view was considered by the host to be non-sensitive. The cameras proved a useful secondary layer of defence when some of the seals were tampered with during the exercise. Notional footage proved that a facility employee, who had not been briefed on the exercise activities, had pulled on a door.

The inherent advantage of using cameras is that inspectors have an image to work with. But how that information is handled by inspectors and hosts is less clear-cut. Their use needs further consideration if it were to be deployed for monitoring purposes within actual nuclear weapons complexes and therefore represents a potential area for future research. Significantly, however, exercise participants felt that CCTV can play a useful role in the monitoring of areas where major security or proliferation risks are not present, or likely to arise.

Information barrier

As noted earlier, the development of information barrier technology represented one of the two major research strands under the Initiative. It was during the monitoring visit that the information barrier and managed access strand merged together.

The information barrier was used to confirm that the initial container, declared to hold the Odin weapon, had a gamma radiation signature compatible with a declaration made by the host. After each stage of dismantlement, the information barrier system was deployed to confirm that the reading from the container holding the weapon's fissile components and the declared signature matched. All other containers were then monitored with non-barriered radiation detectors to confirm the absence of any radioactive material.

Information barriers proved an indispensible component to the verification regime tested by the exercise. They bolstered confidence in the process significantly.

Documentation

To reach more conclusive solutions for the authentication problem in absence of direct access, inspectors made use of a number of redacted documents provided by their hosts. These documents contained a brief history of the Odin class weapon, including measurements, serial numbers, dates and signatures. In and of themselves, documentation carries limited value only as they can be easily falsified. Inspectors were quick to highlight that confirmatory measurement would be needed to supplement documentation. Documents, however, represent an added confidence building measure and it is in this light that they should be seen.

Host techniques for controlling inspectors

During the monitoring visit, Torland employed a range of techniques of its own in order to control the inspection activities:

- Identity checks before and during the visit
- Security briefings

- Changes of clothing and metal detector checking
- Escorting and guarding
- Host control of equipment and measurements
- Shrouding and exclusion zones
- Documentation and information control (including numbered notepads)

Torland also requested a brief resume of each of the Luvanian inspectors prior to the monitoring visit in order to perform (notional) security and background checks. This information was then checked against proof of identity each time inspectors passed between a designated low-security area, where the inspector station was located, and the high-security area containing the dismantlement facility. Torland ensured that Luvanian inspectors could not bring any covert monitoring devices into the facility by requesting that contraband items (such as mobile phones or watches) be handed over before inspectors could go into the high-security part of the site. Torland confirmed that all such items had been handed over by asking the inspectors to (notionally) change into clothing provided by Torland and by using a metal detector to perform a search.

Then, within the high security area, escorts and guards were assigned by Torland to ensure that inspectors only performed pre-agreed activities. Both guards and facility staff were involved in escorting duties, although lines of responsibility were not always clear. What was clear, however, was that the hosting side did not have enough personnel to support both the security escorting and the inspection activities. At times inspectors were left alone and able to take unsupervised measurements of containers. It was agreed that the escorting concept used was resource-intensive, overly so perhaps, and impractical for application in facilities with limits on personnel numbers. A different concept would be to split the escorting and technical inspection support with respect to activities, objects, equipment or sensitive areas. This might increase the number of facility staff required but it would allow the escorts to study the agreements specific to their particular area of responsibility. Regardless of the concept used, however, what is essential is for all staff to be well drilled in the procedures required—which arguably points to a need for the hosting side to play out in-game dummy runs prior to the arrival of any visiting team.

Torland also notionally ensured that equipment used by inspectors contained no covert monitoring features and did not measure parameters considered either sensitive or proliferative. To do this, all inspection equipment was notionally agreed and certified for use within the facility before the exercise began. Equipment used within the high-security area was supplied by the host. However, despite the verification plan stating that measurements would be taken by host facility personnel under inspector supervision, misunderstandings meant that inspectors were allowed to take all measurements themselves. Torland thus lost control over a major aspect of the verification process.

Shrouding was used to conceal items that could have revealed sensitive or proliferative information. Exclusion zones were marked to identify areas prohibited to inspectors. Shrouding emerged as an issue, though, particularly where tooling used in the dismantlement process was hidden by shrouding since these items could not be sealed. In terms of documentation and note-taking, all numbered notepads and pens used within the high-security area were issued by Torland just prior to inspectors' entry and collected before exit. Torland then reviewed all notes to ensure that nothing sensitive had been recorded.

9.6 Post-exercise reporting

Following the monitoring visit, the inspecting team wrote a post-inspection report that they then passed to their erstwhile hosts for comments. In their report, the inspectors observed that:

- They were able to deploy all techniques deemed necessary to maintain an unbroken chain-of-custody of the declared Odin pit throughout the inspection
- The information barrier system was successfully deployed four times with the presence of notional weapons-grade material (cobalt-60) being confirmed each time
- Host cooperation was exemplary
- As a result of the above, the inspectors felt able to state with high confidence that the objects declared as the Odin weapon and its associated containers moved through the entire dismantlement process
- Further scientific measurements and documentation indicating the provenance of the inspected item could, in the future, provide an even greater level of assurance that the object was in fact an Odin bomb

Norway's hosting team added that it was satisfied that its national security had not been compromised and that non-proliferation concerns had been effectively managed and that inspector requests for extra information had been reasonable and acceptable. They agreed that further technological development was called for, particularly with regard to information barriers, in order to confirm that an Odin weapon was being dismantled as declared.

9.7 Conclusions

The UK-Norway Initiative has made a valuable contribution to the state of knowledge on ways to verify the dismantlement of nuclear warheads. Moreover, the Initiative has done so in a unique manner, by investigating the verification of dismantlement within the groundbreaking context of NWS-NNWS collaboration. It represents the first occasion in which a non-nuclear-weapon state has been directly involved in developing and testing methodologies for dismantlement verification. Thus, it is important to carefully consider and analyse all lessons learned and conclusions drawn from this pioneering format.

The working paper presented by the Initiative to the 2010 NPT Review Conference highlighted a number of conclusions that both principal parties have drawn from their collaborative efforts. First and foremost, the Initiative has shown that it is possible for a NWS and a NNWS to 'collaborate within this field and successfully manage any risks of proliferation' while doing so.[122] By framing verification problems in generic terms, it was found that such an approach substantially minimises proliferation risks and, by extension, allows NNWS to contribute to the development of technical solutions addressing dismantlement verification needs.

Second, both countries concluded that maintaining a robust chain-of-custody in a cooperative dismantlement verification regime is possible 'to a high degree of confidence when the relevant technologies have been developed to the necessary level of functionality.'[123] This reflects a realisation that those concepts used to maintain warhead chain-of-custody during the Initiative are effective enough to gain the confidence of both a NWS and a NNWS. It remains to be noted, however, that not all procedures and equipment used in the chain-of-custody—as opposed to the underlying concepts—are sufficiently developed to yet be applicable to real-world environments. That said, given the level of confidence in the concepts, development of such means and methods may not be that great a challenge.

Third, one of the important issues looked at by the Initiative was the problem of authenticating nuclear warheads: the so-called initialisation problem, which had previously been highlighted by the Department of Energy's dismantlement verification study in 1997. Authentication formed one of the two main research strands pursued by Initiative participants, represented by the development of the information barrier. Despite extensive efforts addressing this issue it was found that the initialisation problem represents 'one of the ongoing issues which requires further consideration before a technical solution can be proposed.'

The information barrier designed and deployed during the Initiative proved itself able to confirm the presence of notional weapons-grade nuclear material (in reality, cobalt-60). However, detecting the presence of radioactive material was not deemed sufficient to allow confirmation of the presence or absence of a nuclear warhead. By comparison, the information barrier system developed under the Trilateral Initiative took into account three different properties of fissile material (i.e. presence of fissile material, its isotopic composition and threshold mass), thereby providing greater confidence that an inspected item was in fact a nuclear warhead. As shown by the UK-Norway Initiative, an information barrier with only the ability to confirm the presence of fissile material significantly diminishes the prospect of satisfactorily resolving the authentication problem.

One important and challenging aspect in the design of any verification regime is the declarations on which verification itself is based. And this is particularly important when the item to be verified consists of nuclear warheads – items traditionally subject to extremely restrictive security and classification measures. The UK-Norway Initiative has highlighted the fundamental link between declarations and appropriate verification methodologies in the design of an inspection regime. Declarations dictate and inform the conduct of verification activities, and the equipment that can be used in meeting verification goals. As such, a great deal hinges on what and how much a NWS is willing to declare. It is, therefore, safe to assume that any NWS preparing to embark upon a dismantlement process involving outside inspectors – whether from other NWS or NNWS – would undertake rigorous risk assessments of the potential for the release of sensitive and/or proliferative information. For verification purposes, subsequent declarations must include sufficient detail to enable effective inspections to take place. The less detailed a declaration is, the more difficult the design of an effective, confidence-inspiring verification regime will be.

One of the most commendable aspects of the UK-Norway Initiative was the comprehensive approach it followed in addressing verification challenges. The way the Initiative was structured around two distinct, but complementary, strands that merged in the exercises themselves made it possible to see how the various components of a dismantlement verification regime interact in the field.

Designing an effective verification regime relies on the cooperation of not only states but between different communities of experts also. And an understanding of the motives and considerations driving different actors is instrumental in the construction and application of such complex arrangements. Which, in a warhead dismantlement regime involving one or a number of NNWS, cannot be taken for granted. It was pointed out in the UK-Norway working paper that national security and proliferation considerations 'permeates everything that [a NWS] host party attempts to do.'[124] For a NNWS seeking to understand the motivations and approach of a NWS, recognition of this fact is key. On a different level, the development of a verification regime also entails close collaboration and the finding of common ground between experts in and across the engineering and arms control communities, in order to address the technical and political dimensions that are inherently intertwined in the verified dismantlement of nuclear weapons.

9.8 Future work

Following the conclusion of major Initiative exercises, many areas in both the information barrier and managed access strands were identified by the UK and Norway as warranting further research and development. In addressing these research gaps, both parties have indicated that they are considering holding a series of 'targeted exercises' that would address some of the issues raised during the Initiative and flagged for future research. Both countries have plans to advance the information barrier system developed under the Initiative toward an ability to detect more warhead features than is the case at present, including grade presence and mass thresholds. Overall, there remains considerable scope for further work addressing the verification of nuclear warhead dismantlement. And although the work of the UK and Norway has made a number of significant contributions, greater international effort is essential in order to resolve various areas that still need further research and development.

At its most fundamental level, the verification of warhead dismantlement operations revolves around controlling the movement of information, equipment and personnel in and through highly sensitive settings. Any inspection regime will have to examine, and apply as necessary, the full range of verification procedures needed to generate an acceptable level of confidence in dismantlement, set against the critical need to prevent the release of sensitive or proliferative information. The UK-Norway Initiative, through its two research strands, has comprehensively examined and emphasised the importance of this dynamic. And in doing so, has provided valuable insights into ways not only to overcome the complexities of any verified dismantlement process, but also on areas where non-nuclear-weapon states can be involved in the years ahead.

10. Report Conclusions

This report has sought to provide readers with a narrative of dismantlement verification exercises and progress over the last 40 years. Yet for all its detail, it has barely scratched the surface of the volume of work that has been carried out up to now. Work, after all, seldom exists in isolation, tending rather to build on the experience of previous generations, the triumphs and the failures, the challenges overcome and the avenues left unexplored. By contextualising the UK-Norway Initiative among the initiatives and efforts of the past, only then can we see what it adds, what it has done the same, what similarities in conclusions there are, and what knowledge gaps remain.

The UK-Norway Initiative was centred on the simulation of on-site inspections. These have been shown to represent a necessary component of a dismantlement verification regime if such a regime is to attain acceptable confidence levels. Unlike the verification of delivery vehicles, verification of warhead dismantlement using national technical means is insufficient to achieve the necessary levels of confidence in the actual process of dismantlement. Inspectors must be allowed access to nuclear dismantlement sites. National security concerns notwithstanding, if inspections are not to be conducted in vain, nuclear-weapon states also need to accept some level of inspection intrusiveness. Above all, a culture of managing the risk of divulging sensitive information must be cultivated if the global nuclear disarmament agenda is to progress further.

The UK-Norway Initiative had several objectives. For the United Kingdom, one important point of the exercise was to enhance non-nuclear weapon state understanding of the complexities involved in nuclear warhead dismantlement. Whether or not practical on-site inspection procedures are worked out was seen as a bonus rather than a critically important objective. One of the key objectives with the Initiative, and in particular the familiarization visit, was to make sure that the inspectors gain sufficient understanding of the processes and procedures that will be undertaken during dismantlement. The simulated dismantlement flow was based on real-life dismantlement operations, but was adapted by Norway to simulate secrecy and add unpredictability.

In general, the inspection team could only have some confidence that the warhead had been dismantled and associated material disposed. However, the host team's openness and cooperative manner contributed to the inspection teams' 'high confidence' finding (see p. 72 above). However, the team needed more documentation to *prove* that the weapon was genuine. A similar finding was reached by the 1997 DOE study which, in addition, pointed to the distinction between transparency and verification. The former *provides confidence* that a declared activity is taking place, whereas the latter *confirms* the activity.

To *confirm* that a specific warhead has been dismantled has been shown to represent one of the most technically challenging aspects of dismantlement verification. The basic problem is to confirm the presence of a device that you are not allowed to know much about. The inner workings of the bomb remain a closely guarded secret. The amount of fissile material, its composition and location within the device is especially sensitive. This is a conclusion reached not only by the UK-Norway Initiative, but also by several verification exercises before that. The notable exception are the Black Sea Experiments, where relatively unrestricted measurements were allowed. The obvious solution is to create a device that filters out the sensitive information from a reading, giving inspectors enough information to reach a conclusion on the items authenticity. Following the work of Trilateral Initiative, UK-Norway Initiative participants jointly developed an authentication device—the 'information barrier' —both to confirm that such equipment could be built and to convince themselves of its technical abilities. The information barrier concept should be viewed as proven by now. There remains, however, considerable room for improvement, both in terms of information barrier technology and other means of addressing the authentication problem. In particular, the UK-Norway Information barrier concept did not address the sensitive link between the barrier and the sensor itself. The sensor always sees the complete picture, and that information can be siphoned off or altered before it goes through the information barrier software; more work needs to be done here.

The UK-Norway Initiative also did not sufficiently address the question of equipment authentication (although the issue was discussed at several meetings). Modifying equipment to give a fake reading is an old evasion technique. During Field Test FT-34 equipment was modified to indicate a lower then actual level of purity. This led the inspectors to believe that more material had been produced than was the case. The detection rate in the 1960s was only four per cent; a seemingly low number, but still enough, in the view of the FT-34 final report, to dissuade the evader. After all, if there are 20 instances of cheating, each with a four per cent probability of detection, the probability of catching one act jumps to close to 56 per cent.

Of course, a higher detection rate is nevertheless desirable. The Trilateral Initiative did not solve the question of equipment authentication, and neither did the UK-Norway Initiative. How can the inspector be sure that the equipment he or she is using has not been tampered with beforehand? One solution is for the inspected party to produce the equipment in multiple copies. The inspector can then takes a sample away for review, while the remaining systems are placed under seal under seal. This is the most workable solution, since it allows the inspected party to ensure that the equipment is not rigged to collect and divert classified data, while the inspector, if the sample size is large enough, can be confident that the equipment will not show false readings. The UK-Norway Information barrier was being designed with that in mind. If several pieces of equipment are produced, all involved will have an interest in holding down the cost of the individual unit.

Each unique piece of equipment poses its own authentication challenges and will require its own authentication procedure. It is a different exercise to authenticate, say, a camera than it is to authenticate a piece of software. Again, much more work is needed in this area.

Maintaining a credible chain of custody of the treaty limited item remains exceptionally important. The chain of custody, it may be recalled, 'demonstrates that an unaltered or uninterrupted custody or control of an item has been maintained by the owner or inspector, depending on the monitoring protocol, that provides confidence that deceptions have not been introduced'. In the UK-Norway Initiative, the chain of custody began with entry of the warhead into the dismantlement facility and ended with the placement of the extracted pit in monitored storage.

Several inspectors during the UK-Norway Initiative exercise asked for more documentation to prove that the item being monitored is, in fact, the declared warhead. Chain of custody started 'too late' to be useful in *confirming* that the monitored item was precisely as declared. Interestingly, both the 1997 DOE Study and the UK-Norway Initiative found that chain of custody needs to start as early as possible, perhaps as early as deployment or storage sites. The inspection regime is likely to receive a confidence boost should inspectors, for instance, watch a warhead being de-mated from its delivery vehicle. It would be optimal if inspectors 'take custody' of the warhead from that point, by for instance placing it in properly sealed and tagged containers.

Another problem relates to inspection frequency, and inspector attendance. The 1997 DOE study, for instance, found that a permanent inspector presence led to the highest confidence in the quantity of warheads dismantled. Maintaining a notable inspector presence was important in the UK-Norway Initiative as well, as the seals employed were not designed to be applied in the long term. If inspectors cannot be present, they would naturally seek some way of knowing that nothing untoward is happing in their absence. Sealing an area can, for instance, give some assurance that nothing has been introduced or removed from the area under seal. Putting the area under some form of surveillance, such as under CCTV, would supply additional confidence.

Establishing and maintaining a robust chain-of-custody of a warhead undergoing dismantlement is a challenging, but by no means an insoluble, problem. Further research into this area can address a wide range of techniques and technologies. Some are already well-known and available off the shelf, some more esoteric, and some, no doubt, yet to be invented. This involves addressing challenges in the development and application of monitoring technologies such as tags and seals, equipment used in their evaluation, and surveillance mechanisms such as CCTV.

All inspection exercises have one thing in common: they all aim to find a balance between the inspector's need for access and the inspected party's need to maintain confidentiality. Indeed, an important aspect of research into the verification of warhead dismantlement, as reflected by all studies examined by this report, is the management of the potential proliferation risks associated these activities. This danger is real, and obviously has to be properly addressed, especially where a NNWS is involved, given the non-proliferation obligations contained in the NPT. The management of proliferation risks must be among the highest priorities for any joint endeavour—even in technical studies conducted between, or among, non-nuclear weapon states.

All studies and practical exercises also seem to acknowledge that the number of potentially exposed secrets increase, perhaps exponentially, with the level of access afforded to inspectors. Chillingly, the UK Study Series acknowledge that it is possible to reverse engineer design information from raw radiometric data. Field Test FT-34 showed that some design secrets were exposed even at the lowest access levels, but that was mostly because no attempt was made to protect them. The report warns that it is 'unlikely that all information of use to a foreign government could be protected'. The Trilateral Initiative simply found that the proliferation and security risks associated with monitoring arms reductions were too high for comfort.

For their part, inspector confidence increases with the level of access given. Consequently, if the protection of classified information is of supreme interest, inspection access will be poor, with a corresponding loss of inspector confidence. Later studies come to similar conclusions, but are a bit more moderate. Both the 1997 DOE study, the Trilateral Initiative, and the UK-Norway Initiative concludes that it is possible to give inspectors access while at the same time protecting the inspected party from inadvertent loss of classified information. This conclusion is underpinned by the UK verification research programme.

The UK-Norway Initiative took note of this, recognizing that inspectors and hosts have 'competing priorities' but also that both share a joint interest in the success of the verification regime and in demonstrating compliance. No exercise, however, has ever attempted to explore where the inspector's demand for information optimally intersects with what the inspected party is willing to supply. The UK-Norway Initiative primarily concerned itself with the proliferation risks arising from the exercise itself, and put less emphasis on evaluating the proliferation risks of real dismantlement verification. It is probably worthwhile considering this aspect in further detail in future exercises.

One way of protecting confidential information is by managing access to sensitive areas or operations. The FT-34 report refers to this as 'shielding'. The UK-Norway Initiative referred to its own on-site inspection exercise as an exercise in 'managed access' techniques. Again, the Initiative exercise strongly suggests that that it is possible for uncleared personnel to get access to a classified environment while protecting sensitive information. However, managed access conditions generated at times heated debates between the two sides, with the Norwegians claiming that the UK side was pushing them to provide more access just to 'probe the limits of the envelope'. The reasons as to why access is refused have to be explained to the inspector, as abuse of managed access rights can create both suspicion and concern. The inspector will naturally judge any restriction on his or her access on the basis of the explanations and accounts that the host offer for the shrouded item or area. The Norwegian hosts in the UK-Norway Initiative had a very restricted approach to restricting inspector access. Access was given unless a national security or proliferation reason could be found to indicate otherwise. This approach was often bitterly contended by the Norwegian head of security; he preferred for the UK side to argue as to *why* they needed a certain piece of information. Nothing was offered.

No research thus far has managed to strike a reasonable balance between inspector access and host restrictions. The dangers can be acute in areas where fissionable material is being processed. As early as in the 1960s, the FT-34 final report noted that great care must be taken in cleaning those areas so that small samples of material which may reveal classified material cannot be collected. It also noted that the gathering of micro-samples by inspectors 'could be inconspicuous to host escorts'. The UK-Norway Initiative solved this particular problem by requiring that inspectors change clothes before gaining access to the facility. Inspectors were also subjected to search. They could obviously not bring in napkins or tissues, despite several inspectors having severe colds.

Undeniably, more research needs to be invested into what access is necessary for the inspectors to carry out their mission, and what access is reasonable to provide, given the nuclear weapon state's non-proliferation obligations and national security concerns. These studies should not only examine technical factors. They should also address the human factor. Away from the nuts and bolts of verification, the human factor remains a largely unexplored aspect of arms control monitoring. Human beings have a tremendous ability to observe, deduce and imagine from limited data-sets, yet most verification exercises almost see the human inspector as a pawn to be moved around on a facility chess-board. There is, as a result, scope for more psychologically-oriented studies into dismantlement verification to be undertaken in the future. Trust and confidence between an inspector and an inspected party is vitally important if a verification exercise is to be a success. And at the risk of stating the obvious, once built, trust and confidence need to be nurtured and maintained. They cannot be assumed or taken for granted. If broken, they may stay broken for a long time. In any circumstances, a breach of trust is exceptionally difficult to recover from.

To reiterate a point stressed by most major studies of dismantlement verification, the construction of a dedicated dismantlement facility is an idea worthy of serious consideration. Carrying out dismantlement in a dedicated facility would, in many ways, be preferable to current arrangements where dismantlement activities take place in existing nuclear weapons facilities. Most exercises, including the ones held under the UK-Norway

Initiative, have found that engaging in dismantlement verification in an active facility causes disruption to day-to-day activities. Managing the verification exercise to ensure that inspectors are kept away from day-to-day operations—if for no other reason than to ensure their own safety—often presents a major headache for site operators. Problems such as these would be eliminated in a facility exclusively built for the purpose of warhead dismantlement.

In addition, such facilities can be designed and built in ways that incorporate and facilitate verification activities. In a dedicated facility built to a commonly agreed design, inspectors would be able check the plant against the floor plan before inspection activities commenced to make sure that no hidden trapdoors, concealed spaces, extra piping, or other undeclared constructions had been secretly incorporated. This would help in ensuring that no items could be swapped or spoofed during dismantlement operations conducted out of inspector's sight. The benefits of a dedicated, verification-oriented facility are obvious, but that said, construction costs might easily spiral and such a facility would in any case require separate environmental, safety, and health assessments, a separate security evaluation, and an operational readiness review. Not an easy task, nor a quick one. Despite its cost, it would, however, make the task of providing inspectors access to the facility much easier. It would also, quite naturally, make the verification task much simpler.

It will quickly become complex, however, if a future verification regime will require access to an operational nuclear weapons complex. Inspector access will depend on several factors: the nuclear weapon state's non-proliferation undertakings are one, its national security regulations another one. Indeed, even the nuclear weapon state's health and safety regulations will play a constricting role.

The UK-Norway Initiative assumed that no dedicated dismantlement facility was built. One unique feature of the UK-Norway Initiative, surprising in light of it examining verification options in an operational nuclear weapon complex, was its focus on involving non-nuclear weapon state personnel. Most exercises have in the past been unilateral undertakings keeping within the boundaries of nuclear-weapon states. Before UK-Norway Initiative the only significant attempt to involve non-nuclear weapon state personnel was the Trilateral Initiative, which brought the IAEA into the picture. Even then, however, a large component of IAEA personnel came from nuclear-weapon states. The UK-Norway Initiative thus represents a truly unique effort—two parties from across the nuclear weapons divide working jointly toward a common solution. Finding joint solutions will become increasingly important as nuclear weapon states transform themselves into non-nuclear weapon ones. This aspect is often overlooked in light of the magnitude of the task of just getting the nuclear-weapon states themselves to reduce numbers to low levels. However, it should not be glossed over.

It should be recalled that Article VI of the Nuclear Non-Proliferation Treaty calls on 'all states' to take measures towards nuclear disarmament. This obviously implies that taking practical steps towards nuclear disarmament are a shared responsibility, not only one that falls on the nuclear weapon states. Legal obligations notwithstanding, there is also a practical imperative. As Des Browne said in 2008, in his then capacity as UK secretary of defence, it is 'of paramount importance that verification techniques are developed which enable us all—nuclear-weapon states and non-nuclear-weapon states—to have confidence that when a state says it has fully and irrevocably dismantled a nuclear warhead, we all can be assured it is telling the truth.'

Scientific collaboration between nuclear and non-nuclear-weapon states in this regard is both an achievable and a sensible goal. On the one hand, it allows those in the laboratory of the nuclear-weapon state to escape the intellectual confines of their classified environment. And on the other, it allows those among the non-nuclear-weapon states of the world to grasp the many intellectual and practical problems that face those in the weapons camp. On the outside, it allows the public to gain some idea of the many scientific, technical and procedural steps, and obstacles, that lie ahead.

Technical collaboration will continue to be exceptionally important in the future, and practical exercises particularly so. At VERTIC, from our experience of working with the UK and Norway as well as our examination of previous studies, we can conclude that practical exercises can play an important role in exploring and testing various verification choices for nuclear disarmament. Both Field test 34 and the UK-Norway Initiative have shown the value added by running full-scale simulations of dismantlement verification regimes.

Table-top studies, on the other hand, such as the 1997 report produced by the US Department of Energy, have their merits also. They are (relatively) cheap, and can produce valuable results. But they simply cannot replicate the confusion, frustration and nervousness of a real inspection exercise, even if such exercises are themselves mere approximations of reality. Working in the field allows an inspection team to overcome laboratory 'loss of perspective', to trial concepts and to identify weaknesses that might remain unnoticed on paper.

Careful examination of the UK-Norway Initiative as well as previous studies has revealed nuclear weapons dismantlement processes, and their verification, to be highly complex and fraught with potential dangers relating to security and non-proliferation as well as health and safety. Nonetheless, verification studies undertaken so far have developed and applied innovative and promising approaches to overcome the variety of challenges involved in the monitoring of warhead dismantlement operations. It is therefore, possible to state that, despite a number of unsatisfactorily resolved hurdles, there is nothing to suggest that the verification of warhead dismantlement is not technically feasible. And nothing, moreover, to suggest that dismantlement verification cannot be kept within acceptable levels of tolerance—both in terms of intrusiveness and reliability.

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16 Office of Arms Control and Nonproliferation, 1997, pp. 37-39.

17 Bukharin 2002, p. 191.

18 Office of Arms Control and Nonproliferation, 1997, p. 38. According to Oleg Bukharin, non-nuclear components not intended for re-use are sent either to other DOE facilities or to commercial companies for ‘recycling, recovery of valuable materials or disposal’ Bukharin 2002, p. 191.

19 Bukharin 2002, p. 186.

20 Bukharin 2002, p. 187.

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22 In September 1965, the US ambassador to the United Nations, Arthur Goldberg, repeated to the UN General Assembly an April 1963 US pledge to transfer 60,000 kilograms of weapons-grade U-235 to non-weapons uses if the Soviet Union would similarly transfer 40,000 kilograms of its weapons-grade U-235. Importantly, such transfers would require both sides to dismantle sizable numbers of their existing nuclear weapons in order to gain access to the fissile material contained within. See, for instance, (Committee on Foreign Relations, 1976, p. 109).

23 A jointly financed initiative of the US Department of Defense and the US Arms Control and Disarmament Agency, Project CLOUD GAP was established in 1963 to carry out field exercises—using both military personnel and civilian technicians—to test the feasibility of theoretical arms control and disarmament measures. The project was discontinued after several members of a mock inspection team were killed in a helicopter crash. See, for instance, Herken, G. (1992). Cardinal choices: presidential science advising from the atomic bomb to SDI. Stanford, CA: Stanford University Press., p. 305.

24 Weapons Evaluation and Control Bureau, 1969, p. 3. The US Atomic Energy Commission later evolved into the Department of Energy (DOE). Hence, the following section on the DOE’s 1997 study of warhead dismantlement refers to Pantex and Y-12 as being DOE-run.

25 Weapons Evaluation and Control Bureau, 1969, pp. 27-31.

26 Weapons Evaluation and Control Bureau, 1969, p. 29.
27 Weapons Evaluation and Control Bureau, 1969, p. 31.
28 Weapons Evaluation and Control Bureau, 1969, p. 38.
29 Weapons Evaluation and Control Bureau, 1969, pp. 37-38.
30 Weapons Evaluation and Control Bureau, 1969, pp. 37-38.
31 Weapons Evaluation and Control Bureau, 1969, pp. 37-38.
32 Id. 'This phase was primarily conducted at the Pantex facility, however, the credibility of the components inspected at Paducah was also considered.'
33 Weapons Evaluation and Control Bureau, 1969, p. 7. Note Appendix D, p. 68: 'In addition to [various] physical changes made on the fake weapons, all weapons used in the test. . .were spray painted various colours on a random basis. The purpose of the painting was twofold: to conceal machining and handling marks which might reveal real or fake information and to present to the inspectors weapons which were slightly altered from the way they appeared in the field. This slight alteration in appearance, which was intended as a mild confusion factor, was used in lieu of major modifications and repackaging which would have completely masked weapon identities and relegated inspector prior knowledge to a very minor consideration. Such modification would have been costly and time consuming and was therefore ruled out early in the test planning stages.'
34 Weapons Evaluation and Control Bureau, 1969, Appendix D, p. 52.
35 Weapons Evaluation and Control Bureau, 1969, p. 76. 'Many items of classified information were revealed because inspectors were allowed to examine and look inside nuclear component shipping containers. No attempt was made to alter the containers or to deny access to them.'
36 Weapons Evaluation and Control Bureau, 1969, pp. 76-77.
37 Weapons Evaluation and Control Bureau, 1969, pp. 9, 82.
38 Weapons Evaluation and Control Bureau, 1969, p. 88.
39 Weapons Evaluation and Control Bureau, 1969, p. 94.
40 Weapons Evaluation and Control Bureau, 1969, p. 9.
41 Weapons Evaluation and Control Bureau, 1969, p. 109.
42 Weapons Evaluation and Control Bureau, 1969, p. 98
43 Weapons Evaluation and Control Bureau, 1969, p. 105.
44 Weapons Evaluation and Control Bureau, 1969, Annex F, p. 6.
45 Weapons Evaluation and Control Bureau, 1969, p. 11.
46 Weapons Evaluation and Control Bureau, 1969, p. 117.
47 Weapons Evaluation and Control Bureau, 1969, p. 108.
48 Weapons Evaluation and Control Bureau, 1969, p. 11. Annex F (page 6) clarifies that in addition to complete access to the nuclear weapons themselves, inspectors 'would need to make laboratory examinations of some components to be absolutely convinced that the weapons were bona fide.' Similarly, page 119 of the Final Report notes that if inspectors are to be 'absolutely certain' that bona fide weapons are being destroyed then they 'must have complete access to the weapons and elaborate laboratory facilities for detailed and minute measurements and analyses.'
49 Weapons Evaluation and Control Bureau, 1969, p.120.
50 Weapons Evaluation and Control Bureau, 1969, p. 113.
51 Weapons Evaluation and Control Bureau, 1969, p. 11.
52 Weapons Evaluation and Control Bureau, 1969, p. 110.
53 Weapons Evaluation and Control Bureau, 1969, p. 120.
54 Weapons Evaluation and Control Bureau, 1969, p. 115.
55 Weapons Evaluation and Control Bureau, 1969, p. 12.
56 Weapons Evaluation and Control Bureau, 1969, p. 126.
57 Cochran, T. B. (1989). Black Sea Experiment Only a Start. Bulletin of the Atomic Scientists, 45 (9), pp. 13-16.
58 Belyaev, S., Lebedev, V. I., Obinyakov, B. A., Zemlyakov, M. V., Ryazantsev, V. A., Armashov, V. M., et al. (1990). The Black Sea Experiment: The Use of Helicopter-Borne Neutron Detectors to Detect Nuclear Warheads in the USSR-US Black Sea Experiment. Science and Global Security , 17, pp. 186-193.
59 Fetter, S., Frolov, V. A., Miller, M., Mozley, R., Prilutsky, O. F., Rodionov, S. N., et al. (1990). Detecting Nuclear Warheads. Science & Global Security, 1, pp. 225-302, and Fetter, S., & Von Hippel, F. (1990). US and Soviet reports from a cooperative verification experiment. Science & Global Security, 1 (3), pp. 323-327.

60 Cochran, 1989, p. 14; Fetter & Von Hippel, US and Soviet reports from a cooperative verification experiment, 1990, p. 235 and Fetter, et al., 1990, p. 833.
61 Cochran, 1989, p. 15.
62 Fetter & Von Hippel, US and Soviet reports from a cooperative verification experiment, 1990, p. 235.
63 Belyaev, et al., 1990, pp. 186-187.
64 Belyaev, et al., 1990, p. 188.
65 George Bush Presidential Library and Museum. (1 June 1990). Public Papers - 1990 - June. Retrieved 22 June 2010, from http://bushlibrary.tamu.edu/research/public_papers.php?id=1937&year=1990&month=6.
66 Unless otherwise stated, this chapter is based on Office of Arms Control and Nonproliferation. (1997). Transparency and Verification Options: An Initial Analysis of Approaches for Monitoring Warhead Dismantlement. Washington: US Department of Energy.
67 Office of Arms Control and Nonproliferation, 1997, p. 44.
68 Office of Arms Control and Nonproliferation, 1997, p. 45.
69 Office of Arms Control and Nonproliferation, 1997, p. 46.
70 Office of Arms Control and Nonproliferation, 1997, p. 47.
71 Office of Arms Control and Nonproliferation, 1997, p. 48.
72 Office of Arms Control and Nonproliferation, 1997, p. 3. The DOE study suggested that the Device Assembly Facility at the Nevada Test Site could possibly be used as a dedicated dismantlement facility in the future 'as a means of minimizing the impact of ongoing operations at the Pantex Plant.' (see page 29).
73 Shea, T. (2001). Report on the Trilateral Initiative: IAEA verification of weapon-origin material in the Russian Federation & the United States. IAEA Bulletin, pp. 49-53.
74 Arrangements entered into by NWS with the IAEA under which they voluntarily submit nuclear material and facilities to Agency safeguards. See International Atomic Energy Agency. (undated). The Safeguards System of the International Atomic Energy Agency. Retrieved 12 August 2010, from IAEA Web site: http://www.iaea.org/OurWork/SV/Safeguards/safeg_system.pdf.
75 Shea, T. (May 2008). The Trilateral Initiative: A Model For The Future? Retrieved 12 August 2010, from http://www.armscontrol.org/act/2008_05/PersboShea.asp%2523Sidebar1.
76 Bunn, M. (10 March 2003). IAEA Monitoring of Excess Nuclear Material. Retrieved 12 August 2010, from http://www.nti.org/e_research/cnwm/monitoring/trilateral.asp.
77 Shea, The Trilateral Initiative: A Model For The Future?, 2008.
78 Rauf, T. (2006). A cut-off of production of weapon-usable fissionable material: considerations, requirements and IAEA capabilities. External Relations and Policy Coordination. Vienna: International Atomic Energy Agency.
79 Shea, The Trilateral Initiative: A Model For The Future?, 2008.
80 Shea, The Trilateral Initiative: A Model For The Future?, 2008.
81 Shea, Report on the Trilateral Initiative: IAEA verification of weapon-origin material in the Russian Federation & the United States, 2001, p. 51.
82 Shea, The Trilateral Initiative: A Model For The Future?, 2008.
83 Rauf, 2006, p. 11.
84 Shea, The Trilateral Initiative: A Model For The Future?, 2008.
85 ElBaradei, M. (September 2002). Statement to the 46th IAEA General Conference. International Atomic Energy Agency.
86 Shea, The Trilateral Initiative: A Model For The Future?, 2008.
87 Shea, The Trilateral Initiative: A Model For The Future?, 2008. Under the agreement will proceed to complete and operate facilities that will dispose of at least 34 metric tons of weapons grade plutonium by using it as fuel in civil power reactors to produce electricity. The PMDA also provides that additional weapon-grade plutonium declared excess, as arms reductions go forward, should be disposed under the same or comparable transparency and other terms. Disposition activities on both sides will be subject to monitoring and inspections. America.gov. (13 April 2010). 2000 Plutonium Management and Disposition Agreement. Retrieved 13 August 2010, from http://www.america.gov/st/texttrans-english/2010/April/20100413172618xjsnommis0.4895397.html.
88 Quoted in Shea, The Trilateral Initiative: A Model For The Future?, 2008.
89 Secretary of State for Defence. (1998). Strategic Defence Review. London: UK Ministry of Defence.
90 AWE. (2000). Confidence, Security and Verification: The challenge of global nuclear weapons arms control. Reading: AWE.
91 United Kingdom. (2005). Verification of nuclear disarmament: final report on studies into the verification of nuclear warheads and their components. Working Paper, New York.

92 Reaching Critical Will. (2000). UK: Nuclear Verification. Retrieved 12 August 2010, from http://www.reachingcriticalwill.org/legal/nwc/mon2uk.html.
93 United Kingdom. (2003). Verification of nuclear disarmament: first interim report on studies into the verification of nuclear warheads and their components. Working Paper, New York, p. 2.
94 United Kingdom, 2005, p. 2.
95 AWE, 2000, p. 12.
96 United Kingdom, 2003, p. 2.
97 AWE, 2000, pp. 13-16.
98 United Kingdom, 2003, p. 3.
99 United Kingdom, 2003, p. 3.
100 United Kingdom, 2004, p. 3.
101 United Kingdom, 2004, p. 5.
102 United Kingdom, 2004, p. 5.
103 Levels detected were noted to pose no health and safety concerns.
104 United Kingdom, 2004, p. 7.
105 United Kingdom, 2004, p. 8.
106 United Kingdom, 2004, pp. 9-10.
107 United Kingdom, 2005, p. 3.
108 United Kingdom, 2005, p. 4. Similarly the AWE's 2000 study noted that the objectives of monitoring a nuclear weapons complex 'include both ensuring that warheads are dismantled and that no further warheads are added to the stockpile beyond any agreed level.' AWE, 2000, p. 32.
109 United Kingdom, 2005, p. 4.
110 AWE, 2000, p. 34.
111 United Kingdom, 2005, p. 4.
112 United Kingdom, 2005, p. 4.
113 High resolution commercial satellite imagery 'looks for evidence of relevant activities on the ground and is being evaluated in relation to nuclear sites for its value to the verification process' United Kingdom, 2005, p. 5.
114 Hyperspectral imaging systems 'acquire data over a range of wavelengths in the visible, short- and long-wave infrared (thermal) regions of the electromagnetic spectrum.' United Kingdom, 2005, p. 5.
115 Plant stress is a measure of the variation in chlorophyll content in living plants, in response to pollutants. 'Emissions from industrial facilities may induce pre-visual plant stress in the surrounding environment. Hyperspectral imaging has been used as a tool to monitor the plant stress induced in plants that naturally bio-accumulate certain chemical species. The examination of multi-spectral visible/near-infrared high-resolution satellite imagery for indications of plant stress in the environment is ongoing. As a verification tool it would be necessary to have the capability to detect very small changes and, of course, to be able to account for baseline plant stress effects from unrelated natural events.' United Kingdom, 2005, pp. 5-6.
116 The 2005 UK working paper noted that past research has shown that it is 'possible to detect material and ground contamination from nuclear industrial processing activities using airborne gamma spectroscopy from a low-flying platform.' Within the UK research programme, the technique's verification utility was examined 'by calculating detection and false alarm probabilities for various situations.' (United Kingdom, 2005, p. 6.)
117 As part of its work, the UK considered the possibility of monitoring electricity, water and fuel oil consumption as an aid to verification, and postulated that: 'It might be possible to provide metering for individual items of manufacturing equipment (e.g. an induction furnace) to detect frequency and duration of use or to monitor the purchasing of certain chemicals common to production and finishing operations, such as chlorinated volatile organic compounds.' United Kingdom, 2005, p. 6.
118 United Kingdom, 2005, p. 12.
119 United Kingdom, 2005, p. 12.
120 Acton, J. M. (2007). Discussion Paper No 1: Information barriers: A Non-Nuclear Weapon State Perspective. Oslo: Norwegian Study Group on Disarmament and Non-Proliferation. Persbo, A., & Bremer-Maerli, M. (2007). Discussion Paper No 2: Peer-review of the UK working papers on nuclear disarmament verification, presented at the 2005 NPT RevCon and preceding PrepComs. Oslo: Norwegian Study Group on Disarmament and Non-Proliferation.
121 See Gosnell, T. B. (2000). Uranium Measurements and Attributes. Livermore: Lawrence Livermore National Laboratory.
122 Norway and United Kingdom, 2010, pp. 15-16.
123 Norway and United Kingdom, 2010, p. 15.
124 Norway and United Kingdom, 2010, p. 16.