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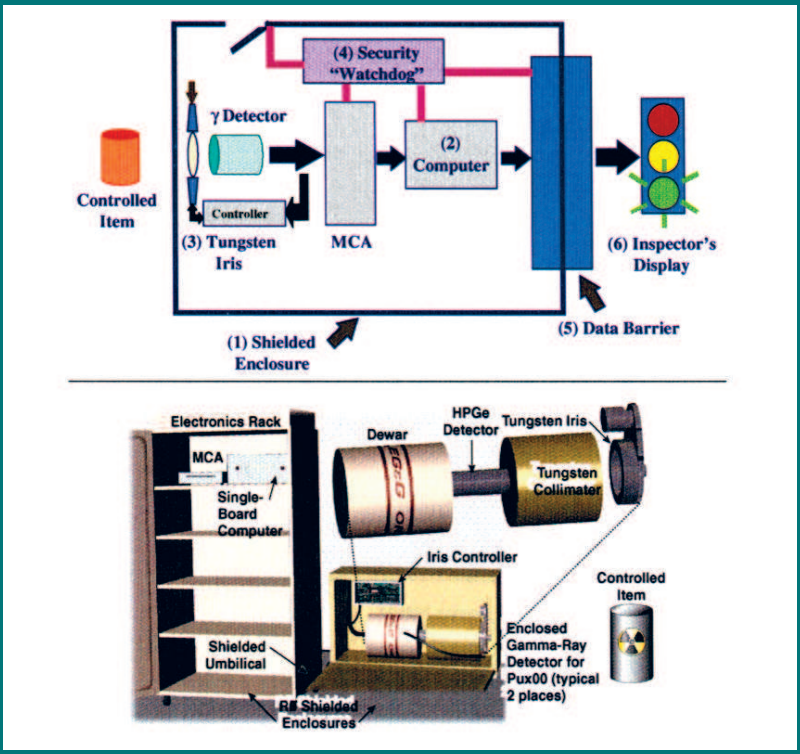
VERIFICATION OF NUCLEAR WEAPON DISMANTLEMENT

Peer Review of the UK MoD Programme



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About British Pugwash

British Pugwash is the UK arm of Pugwash Conferences on Science and World Affairs, an international network of scientists and experts on international affairs, which seeks to inform government and the public on matters relating to science and world affairs. Carrying on the work that Joseph Rotblat and his colleagues began, it aims to bring scientific insight and reasoning to bear on threats to human wellbeing arising from the application of science and technology, and above all from the threat posed to humanity by nuclear and other weapons of mass destruction. It is also concerned with questions relating to the social responsibility of scientists, and the quest for an end to war itself.

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British Pugwash believes that we are living in challenging times, in which many established patterns of domestic and international behaviour are being questioned, and that there is a very real opportunity to influence political developments by urging that decisions should be based on good science and rationality.

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Cover illustration:
Block diagram and illustration of a hypothetical gamma ray inspection system with an information barrier. The key elements of the information barrier include: (1) opaque, grounded conducting enclosures, which prevent telltale EM emanations from the electronics; (2) simplified acquisition and analysis computer with most components on a single board; (3) tungsten iris, which opens and closes to optimize the live time of the measurement while keeping the included solid angle uncertain; (4) “Security watchdog” which activates on indications of events which threaten data security (e.g., opening of the enclosure); (5) data barrier, which isolates via optical fiber or some other one-way transmission path, and (6) the simplified user display.

From J. K. Wolford Jr. and G. K. White ‘Progress in Gamma Ray Measurement Information Barriers for Nuclear Material Transparency Monitoring’. Article submitted to The Institute of Nuclear Materials Management Annual Meeting, New Orleans, LA, July 16-20, 2000. Figure 3.

Verification of Nuclear Weapon Dismantlement

Peer Review of the UK MoD Programme

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Nevertheless, we should make it clear that the views expressed, and conclusions drawn, in this report are those of the authors and do not necessarily reflect the opinions of MoD.

Acronyms

ACDA	Arms Control and Disarmament Agency (US)
ADA	A structured, wide-spectrum, and object-oriented high-level computer programming language, extended from Pascal and other languages, that was designed between 1977 to 1983 to supersede the hundreds of programming languages then used by the DOD. It was named after Ada Lovelace (1815–1852), who is sometimes credited as being the first computer programmer.
AEC	Atomic Energy Commission (US)
AWE	Atomic Weapons Establishment, Aldermaston, UK
BPG	British Pugwash Group
DOD	Department of Defense (US)
DOE	Department of Energy (US)
Dstl	Defence Science & Technology Laboratory
IAEA	International Atomic Energy Agency
INMM	Institute of Nuclear Materials Management
MoD	Ministry of Defence (UK)
NDT	Non-destructive testing
NGO	Non-governmental organisation
NPT	Nuclear Non-Proliferation Treaty
NWS	Nuclear-weapon State (under the NPT)
P5	The five permanent members of the UN Security Council
PrepCom	NPT Preparatory Committee
RevCon	NPT Review Conference
SIPRI	Stockholm International Peace Research Institute
START 1	Strategic Arms Reduction Treaty

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Verification of Nuclear Weapon Dismantlement

1. Introduction

This work was carried out at the request of the Head of Strategic Technologies at the Ministry of Defence (MoD) during the period March-December 2011. It draws on information provided at an unclassified workshop held at University College London on 10 March, at which MoD and Atomic Weapons Establishment (AWE) staff made presentations on the UK programme, and on more detailed information provided to security-cleared members of the British Pugwash Group (BPG) at Aldermaston on 4 April and at MoD on 24 November. Lists of BPG participants in these meetings are given in Annex 1. Following the first classified meeting, a discussion was held among the members of the BPG team on 21 April, at which a number of requests for further clarification were formulated. These were discussed with MoD and AWE staff at a meeting in London on 27 May 2011.

The BPG team was asked to undertake an independent peer review of the work on this subject undertaken by (or funded by) the UK MoD during the period 2000-2011 (hereinafter 'the programme'), and of its plans for further work during the period up to the next quinquennial review of the Nuclear Non-Proliferation Treaty (NPT) in 2015. It was agreed that the review should exclude work undertaken within the framework of the UK-Norwegian bilateral programme in this area. It was stressed that the review should focus on technical aspects of the work: matters relating to international or national politics, and strategic and economic policy issues, lay outside its scope (and indeed largely lay outside the mandate of MoD). However, it was recognised that the arms control context of this technical work was important, and at the workshop on 10 March, the Assistant Head of Arms Control and Counter-Proliferation Policy (ACP) at MoD gave a useful presentation on this subject.

This presentation emphasised that the verification of compliance with international agreements on nuclear weapon disarmament is seriously constrained by the UK's obligations as a signatory to the NPT. Under Articles 1 and 2, Nuclear-weapon State (NWS) signatories of the NPT are obliged "not to transfer to any recipient whatsoever nuclear weapons or other nuclear explosive devices or control over such weapons or explosive devices directly, or indirectly; and not in any way to assist, encourage, or induce any non-nuclear-weapon State to manufacture or otherwise acquire nuclear weapons". This is widely interpreted as meaning that any information obtained about the design or manufacture of a weapon in the course of verifying treaty compliance may not be transmitted to any other party, and some states (including the UK) interpret it as meaning that the verification process must not reveal any such information to the verifier.

The UK, like other Nuclear-weapon States, also seeks to restrict access to information relating to the design of its nuclear weapons for reasons of national security. The UK programme on verification has been constructed to be compatible with its interpretation of the NPT, and with its own security requirements, and is therefore based on the principles of 'Managed Access' and 'Information Barriers' to ensure that the inspector is never able to access such information. Within the UK programme, MoD has hitherto defined 'dismantlement' as meaning 'making unusable as a weapon'. The resulting material may in due course be used to make nuclear fuel for civilian purposes, or in other ways made unusable in a nuclear weapons programme, but that 'disposition' is a separate activity. MoD made it clear that disposition lies outside the scope of this review.

2. Early work on verification of nuclear weapon dismantlement 1967-2000

Although the early work on this subject also lies outside the scope of this review, some key results of the earlier work should be mentioned here, in order to put the more recent UK work into perspective. What follows here is a very brief summary: for further detail, the reader is referred to an excellent review of this early work written by the VERTIC team, and recently published as an unclassified report[1].

2.1 Early US work: Field Test 34 (1967)

During June-October 1967, the US Department of Defense (DOD) and the US Arms Control and Disarmament Agency (ACDA) undertook a project designated Field Test FT-34, aimed at developing and testing inspection procedures to monitor the demonstrated destruction of nuclear weapons. This project was linked to US proposals around at that time to transfer up to 60 tons of weapons-grade uranium-235 to non-weapons uses. The work was carried out in four US Atomic Energy Commission (AEC) plants – Pantex, Rocky Flats, Paducah and Y-12 – and involved a mixture of real nuclear weapons and fakes. An important feature of the project was that inspection teams of different sizes, and with different levels of access, monitored the destruction of the weapons presented to them, and the project gathered information about the amount of classified information revealed and the credibility of the inspection regime.

The test exercises sought to evaluate the effectiveness of various evasion techniques – for example, attempts to divert some of the fissionable material, or to introduce nuclear materials derived from sources other than weapons. Four identical batches of weapon shapes, totaling 72 weapons in all (40 real, 32 fake to simulate evasion), were presented for dismantlement. When inspectors were given the lowest level of access, less than 50 per cent of their calls with regard to the authenticity of 'weapons' were correct. At the highest level, around 80 per cent were right. The proportion of correct calls did not vary much with team size or composition.

FT-34 also assessed the effectiveness of assay operations on outcoming fissile material. Some 96 plutonium assay operations were conducted, in which evasion was attempted on 48. At most, three of these were detected. No evidence was gathered to suggest that team size played any part in the successful detections. During uranium assay trials, evasion was practiced on 32 sample operations, none of which were successfully identified. Overall, the success rate in the detection of evasions was just 4 per cent. The final report made the point that although this might not seem very high, it represented 'a substantial risk for the evader'. Nevertheless, its bottom line conclusion was that if a high level of certainty is required that a nuclear weapon has been destroyed, a high level of access must be granted to the inspectors. It recognised that this conflicted with the requirement to protect classified information, and argued that an acceptable compromise would have to be agreed.

[1] D. Cliff, H. Elbahtimy & A. Persbo, *Verifying Warhead Dismantlement: Past, present, future*, VERTIC Research Report No 9, London, September 2010

2.2 The Black Sea Experiments (1989)

In July 1989, an American team from the Natural Resources Defence Council, led by Tom Cochran, and a Soviet team from the Academy of Sciences, led by Evgeny Velikhov, took part in a series of joint experiments on board the nuclear-armed Soviet cruiser *Slava*, moored at Yalta in the Black Sea, to determine whether a ban on Submarine-Launched Cruise Missiles on surface ships could be adequately verified. For the purposes of the experiment, the *Slava* had a single nuclear-armed SS-N12 Sandbox missile on board. This joint experiment was the first occasion on which foreign scientists were allowed to make radiation measurements on an operational Soviet nuclear warhead.

The US scientists used their own high resolution germanium detector. They were given one opportunity to access the warhead directly, and they deployed their detector at a distance of about 70 cm from the centre of the warhead and left it to run for around 20 minutes. They were allowed to record the full gamma spectrum, and no measurement information was withheld.

The Soviet scientists carried out a separate set of radiation measurements. The most successful of these used a helicopter-borne system designated ‘Sovietnik’ to detect and measure neutron emissions at a distance of up to 100-150m from the neutron source. The helicopter flew slowly over the cruiser at a height of 30-80m, and 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.

From subsequent publications by the two groups, the following picture emerges. The American gamma spectrum measurements showed the distinctive peaks of the two fissile isotopes uranium-235 and plutonium-239, and also showed gamma rays from the decay of another isotope (U-232) indicating that the source of uranium used in the warhead was reactor fuel, further processed for weapons use. Analysis of the spectrum also provided information on the isotopic composition and uranium enrichment level. It seems that no sensitive design information or warhead yield was revealed by the single gamma measurement taken by US scientists. Possibly because of the restriction to a single reading, they were not able to infer sensitive design information, such as the distance between the primary and secondary stages in the warhead. (It has sometimes been suggested that the fissile material was not actually a warhead at all).

The measurements from the helicopter-borne Sovietnik system were able to confirm the existence of a neutron source on board the *Slava,* and the system was able to correctly identify the area on the ship housing the source.

The Black Sea Experiment broke new ground by demonstrating the feasibility of a ‘second track’ approach to the verification of nuclear arms control negotiations, and it suggested that mutual confidence between Soviet and US scientists could play a role in developing mutually acceptable inspection regimes. It established the acceptability of making certain gamma ray measurements on a nuclear warhead, even during the Cold War era.

2.3 US Department of Energy (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, 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 to monitor warhead dismantlement[2], and established a Dismantlement Study Group to do the work. Its report was released in May 1997.

This study focused on three key questions:

1. What rate of dismantlement could be achieved?
2. Could a warhead dismantlement monitoring regime work without an Agreement for Cooperation for the exchange of Restricted Data or Formerly Restricted Data?
3. Could the warhead be identified as being of a specific type by implementing monitoring measures only at DOE facilities, or would DOD facilities also have to be involved?

After reviewing a number of past studies[3], the study group analysed the effectiveness of each of ten key monitoring activities, and concluded:

- Any treaty requiring the full range of monitoring to be undertaken within an existing DOE nuclear weapons complex would have a significant impact on its normal operations. So careful planning would be needed to ensure that such a treaty would not affect the DOE's ability to maintain a safe, secure and reliable stockpile of US nuclear weapons. It might be judged preferable to construct a dedicated dismantlement facility.

- To achieve a reasonable level of confidence that the declared dismantlement has taken place, there would probably be a need for an Agreement for Cooperation between the parties to exchange Restricted Data or 'Formerly Restricted Data'.

- To determine whether a submitted item is a genuine warhead or not, and to identify its type, is very difficult, and might require both chain-of-custody procedures from DOD facilities (e.g. 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.

- The rate of verified dismantlement would be influenced by the level of inspector access permitted.

- There was a need for further research on the application of radiation signatures, particularly in view of problems about the degrees of uniqueness of the signatures and the alteration of signatures during the dismantlement process. It might, for example, be difficult to distinguish between warheads of similar type (e.g. Trident I and II).

- To establish a database of 'template' radiation signatures for the relevant weapon systems, it was suggested that these templates could be formed by assembling a number of objects declared by the inspected party to be of the same type. The inspecting party would then select a small number of the objects and record their spectra (either passive spectra or active neutron spectra). Without either side seeing the data, a computer would compare the

[2] *Transparency and Verification Options: An Initial Analysis of Approaches for Monitoring Warhead Dismantlement,* Department of Energy Office of Arms Control and Nonproliferation, 19 May 1997, p. 1
[3] For this report, seven major post-1990 studies relating to warhead dismantlement transparency and verification were reviewed by the study group – see footnote 2

spectra to ensure that they are sufficiently alike before storing the average spectrum as the template for that object type. The template would then need to be securely stored under a dual-lock system so that neither side could have access to it without the other side being present.

- Further research was needed on the Fission-Product Tagging technique, whereby a warhead to be dismantled is irradiated with neutrons prior to undergoing the dismantlement process. Following dismantlement, the abundance ratios of the various fission products (which change with time) in the components extracted from the warhead could be used to determine the time elapsed between the initial irradiation and the post-dismantlement measurement. This would then be compared to the known time of irradiation, and a match would provide evidence of the dismantlement of a specific weapon. And because the signature associated with the initial measurement (made at the time of irradiation) is independent of the design or materials in the weapon, it is the only radiation technique clearly specific to an individual weapon.

- There was a need for further investigation on the amount of sensitive information revealed by different measurement techniques, and the scope for protecting such information.

2.4 The Trilateral Initiative (US, Russia, IAEA 1996-2002)

This joint venture was launched in September 1996 by the International Atomic Energy Agency's then director-general, Hans Blix, to investigate the technical, legal and financial issues associated with IAEA verification of the disposition of fissile material deemed surplus to defence requirements, and to establish an IAEA system of verification which guaranteed that the material would not be reused in, or diverted to, weapons. It was judged that a new system was necessary because the existing IAEA verification techniques could not be applied to classified weapons material without revealing proliferation-sensitive information of the kind prohibited by Article I of the NPT. Because this obligation, although formally expressed in the NPT in terms of nuclear-weapon and non-nuclear-weapon states, logically extends to multinational entities such as the IAEA, the Agency recognised that its access to the US and Russian nuclear weapon complexes would have to be restricted in order to maintain an acceptable level of nuclear secrecy.

The three parties established a Joint Working Group to consider the issues involved. It was recognised that parties submitting such fissile material could not be expected to pre-process it to remove any classified information. It followed that it would not be acceptable for the IAEA to make unrestricted measurements on the material, so the initiative had to develop a procedure employing 'information barrier' technology, designed to block quantitative measurements from view, and provide IAEA inspectors with binary 'pass/fail' readings only. In relation to plutonium, the Working Group eventually settled on three attributes that had 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 mass of metal exceeds an agreed minimum, defined in relation to each facility.

On this basis, 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 a combination of this technique with neutron multiplicity counting to measure plutonium mass. The Trilateral Initiative experts then went on to develop and demonstrate a prototype ‘Attribute Verification System with Information Barrier for Plutonium with Classified Characteristics utilising Neutron Multiplicity Counting and High-Resolution Gamma-ray Spectrometry’ (or simply AVNG).

The Joint Working Group also undertook work on inventory monitoring systems for facilities designed to store weapon-origin fissile material. The system proposed was based on a sampling plan, aimed at detecting a ‘strategic change’ in the inventory, amounting to a break-out of the order of 1 per cent of the monitored inventory. This ‘one-per-cent solution’ was never formally adopted, but served as the de-facto reference for developing the sampling plan.

Consideration was also given to the steps required for the verified conversion of fissile material from classified to unclassified forms and its subsequent disposition. It was agreed that managed access would be allowed into the conversion facility on an annual basis to ensure that no warhead components had accumulated within it, and that no undeclared penetrations existed. IAEA inspectors would be allowed to watch containers entering the measuring system, identify tag measurements, confirm seals and observe pass/fail attribute measurements.

The Trilateral Initiative was brought to a close in September 2002, after a series of nearly 200 meetings. Mohammed ElBaradei, then IAEA director-general, told the Agency's general conference that “preparatory work” under this initiative had been “largely concluded”, and both the Bush and Putin administrations decided that the initiative should be called a success.

3. UK work on verification of nuclear weapon dismantlement 2000-2011

The UK national programme developed out of the earlier work summarised above, in which the US, Russia, and latterly the IAEA sought to define (and in part to develop) technologies which would enable a host nation (the owner of the weapons whose dismantlement was being verified) to give sufficient ‘managed’ access to the inspector to give him confidence that the objects being submitted were indeed weapons with nuclear warheads, and that after the dismantlement process the fissile material contained in them was indeed sent for acceptable disposition.

The starting point for the UK programme was the UK announcement at the 2000 NPT quinquennial review that it had launched such a programme[4]. Two subsequent events which strongly influenced the development of the programme were the suicide attacks by al-Qaeda upon the United States on 11 September 2001, and the speech delivered by Margaret Beckett to the Carnegie Institute on 25 June 2007[5]. The 9/11 attack brought

[4] NPT/CONF.2000/MC.I/WP.6 Working paper on Nuclear Verification, submitted by the United Kingdom of Great Britain and Northern Ireland

[5] “A World Free of Nuclear Weapons?” Keynote Address by Margaret Beckett, Secretary of State for Foreign and Commonwealth Affairs, United Kingdom, Carnegie International Nonproliferation Conference, Washington, D.C., 2007

home the fact that protection against proliferation of nuclear weapon technology did not simply have to be directed against state proliferators – potential non-state agents also had to be taken into account. This line of thought had the implication that verification of nuclear weapon dismantlement had to be carried out in a way which did not disclose weapon design information to any of the individuals involved, regardless of their nationality or organisational credentials. The Beckett speech confirmed that it was UK government policy that the UK should "be at the forefront of both the thinking and the practical work on building a new impetus for global nuclear disarmament – to be, as it were, a 'disarmament laboratory'". This initiative was further strengthened by a speech by the then Defence Minister Des Browne at the Conference on Disarmament that UK expertise in the technology of dismantlement would contribute to the UK as a disarmament laboratory. A limited build-up of staff at AWE devoted to this work has since taken place. In 2000, the team consisted of three full-time staff: this has now expanded to seven, and they are supported by part-time contributions from other parts of AWE, amounting to some 12 MY per year.

With this background, during the period 2000-2008 the UK programme embarked on a series of desk studies and small-scale experiments aimed at developing a coherent approach to verification in this new political climate, while retaining its traditional concern to preserve the nuclear security framework of its own national nuclear weapons programme. The outlines of the resulting programme were set out in working papers submitted to the NPT PrepComs in 2003 and 2004[6] and to the Review Conference in 2005[7], with a further update at the NPT PrepCom in 2008[8].

In summary, the UK programme set itself the objective of devising a set of verification procedures which would give the inspectors a high level of confidence without releasing any proliferative information. It recognised that this objective was at odds with the conclusions reached by the US studies undertaken in 1967 and 1996, but it took the view that verification technology had moved on considerably since those studies. Nevertheless it made provision for the UK programme to identify the gains and losses which might accrue if certain information were released, but it was agreed that the programme should start with an assumption of zero release, if only to discover where the sensitive points lay.

The main basis for the UK's uncompromising stance on the release of proliferation-sensitive information has been its interpretation of the provisions of the NPT – i.e. that there should be no disclosure of information to any party which would assist anybody in designing a weapon. However it is emphasised that the NPT is not the only constraint. National security and safety issues are also important, especially when considering access to facilities, or the process of transport of fissile material, which are regarded as matters of interest to terrorists or other non-state agents. However its bottom line remains that if it can be established that adequate verification is impossible without some release of classified information, some such recommendation could in principle be made to government. But any such release would have to be justified.

[6] Working papers submitted to NPT Preparatory Committee NPT/CONF.2005/PC.IIMP.1 (April 2003) and NPT/CONF.2005/PC.III/WP3 (April 2004)

[7] Working paper submitted to 2005 Review Conference NPT/CONF.2005/WP.1

[8] Presentation by AWE to the NPT Preparatory Committee 2008, 6 May 2008

3.1 Definitions of terms

The term **'dismantlement'** is understood in this context to mean 'making the device unusable as a weapon'. This does not necessarily mean 'making the components unusable in a weapon'. The fissile material, or other components of the device, could in principle be recycled and used for weapon manufacture. However the steps required to prevent this are regarded as **'disposition'**, which is a separate process, not within the scope of this review. The precise boundary between dismantlement and disposition is a matter of debate, since the first stage of dismantlement yields sub-components such as fissile cores, explosives, triggers, electronics, etc, which still embody a great deal of classified information (e.g. the original core geometry and isotopic composition). Moreover, the components could relatively easily be recycled, so it is only after the cores have been through a separate 'safeguards' facility, in which they are shredded, and the fissile material is blended with other material to confuse attempts to measure their isotopic composition, that the material can be made freely available to inspectors. Because of the need for this intermediate processing, the pragmatic definition of 'dismantlement' adopted by UK MoD is that it has occurred when the fissile core has been separated from the surrounding chemical explosives.

The term **'verification'** likewise admits of various interpretations. In Margaret Beckett's Carnegie speech, she identified the task as being to confirm "that an object presented for dismantlement as a warhead is indeed a warhead, and that the items that emerge from the dismantlement process have indeed come from the authenticated object that went into that process to begin with, and are not being returned to use in new warheads". She recognised that it would be a challenge to "create a robust, trusted and effective system of verification that does not give away national security or proliferation sensitive information".

As we have seen in section 2.3 above, the US programme prior to 2000 regarded this objective as probably unattainable: it judged that "determining whether a submitted item is a genuine warhead or not is very difficult, and may require both chain-of-custody procedures from DOD facilities (e.g. 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. If there were a need to distinguish between strategic and tactical warheads, or between warheads of different types, the 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."

On the whole question of the scope of verification, the UK programme to date has taken a cautious stance. Unlike the US programme, which has recognised that, in the verification of certain bilateral treaties, there might be a need to confirm that the item submitted is a particular type of weapon, the UK programme to date has largely been based on a 'scaled-down' requirement described below. However it has not excluded the possibility that specific warhead radiation signatures could be used to confirm that it is the declared type of warhead, provided that these signatures are encrypted in such a way that the classified information which they contain is never revealed to the inspector. It has also not ruled out the possibility of establishing a chain of custody for a weapon container, declared as containing a weapon scheduled for dismantlement, between its military deployment site and the dismantlement facility. It is nonetheless recognised that there are difficulties of principle in establishing that a weapon is indeed of a specified type, if inspectors are never allowed visual and instrumental access during the dismantlement of any such weapon.

The UK dismantlement programme is divided for administrative purposes into two parts – 'authentication' and 'chain of custody', and work on these two topics was reported by the UK to the 2000 and 2005 NPT Review Conferences, with a further update at the 2008 NPT PrepCom. The term **'authentication'** has come to be interpreted, on the scaled-down interpretation of verification, as meaning that the inspector should achieve reasonable confidence that an object introduced into the dismantlement facility in a closed container, contained sufficient fissile material (U-235, Pu-239) in sufficiently pure form for it to be probable that some kind of nuclear weapon was contained within it. Given the constraints of the NPT, it is taken for granted that the inspector will at no stage be allowed to see the contents of the container, or even to see the complete dataset produced by a nearby high-resolution measuring instrument (e.g. a high purity Ge gamma spectrometer). So the procedure has to involve the host in positioning an agreed instrument, and transmitting a redacted version of the measured data across an **'information barrier'**, which is just sufficient to give the inspector the required confidence, but not sufficient for him to infer any aspects of the design of the weapon. The information passed across the barrier might, for example, consists of yes/no answers to questions such as 'does the mass of Pu exceed x kg, and does its isotopic composition exceed y% Pu-239?' However more sophisticated data transfers are not excluded.

The dismantlement process is conducted in a **'dismantlement cell',** an enclosed facility to which the inspector is given 'managed access' – i.e. limited access into the cell before and after (but not during) the dismantlement process – so that he can satisfy himself that there are no pathways by which fissile material could be smuggled out or simulating isotopes smuggled in, and no means by which the host could tamper with the instrumentation so as to give misleading information.

Dismantlement initially leads to a relatively small number of outcoming sealed containers, each holding a group of components (e.g. fissile material, explosives, metallic and organic wastes). These components still embody a great deal of classified information, so they need to be held in a secure monitored storage facility until they can be transferred to the facility undertaking the disposition process. The inspector is not permitted to see inside these containers, or to make unrestricted measurements on them. However some limited measurements can be made at the behest of the inspector, if necessary using information barrier technology to ensure that classified information is not revealed.

As regards the **'chain-of-custody'** programme, the key problem which it addresses is to ensure that the items that emerge from the dismantlement process represent the totality of the materials derived from the dismantlement of the authenticated object that went into it, and that there has been no diversion of materials or substitution by simulants. It is regarded as unrealistic to attempt to keep track of every individual component of the weapon during the dismantling process. So instead, steps are taken to ensure that the number of entry points into the dismantling cell is strictly limited, and each such entry-point is subject to a system of 'portal monitoring', so that only monitored transfers (in or out) of materials (particularly fissile materials) or tools can take place.

To prevent the outcoming material from being recycled, each incoming container is given a unique identifier, in the form of a tag, and each outcoming container is likewise tagged, in a manner which permits these to be correlated. Because of the long timescales involved in dismantling (in some cases the whole process may take several months) it is not realistic for inspectors to maintain continuous personal supervision of each individual item, so a procedure for sealing containers using ‘tamper-resistant seals’ has been developed, enabling the inspectors to confirm that no change has been made to the contents in their absence. In particular, the fissile material container is protected by a Tamper Indicating Device (TID) which will ensure that no fissile material can be diverted while the container is on its way to, or held in, a monitored storage area. The time period over which this chain-of-custody process has to be sustained can be quite considerable – extending up to years if the capacity of the ultimate disposition process is limited.

3.2 UK work on authentication

The UK approach to authentication was set out in the publicly available reports to the various NPT PrepComs and to the 2005 RevCon. Since then, there has been further work, some of which is described in restricted reports or open publications that have been made available to us by MoD (see footnotes [9, 11,13,14]), and this is described below.

Although this has not yet been discussed publicly, the dismantlement programme has devoted some time to considering possible evasion scenarios, and devising effective counters to them. It believes that it could now detect evasions a lot better than was possible forty years ago. It has also considered whether there could be a role for ‘privileged inspectors’, who would be given access to classified information, but it has concluded that this would not be compatible with national security. In any case, it can be argued that the international credibility of the verification process would require the inclusion of inspectors from outside the P5, and there might not be an acceptable source of such inspectors.

3.2.1 The objectives of the authentication process

Ideally, one might wish that the authentication process demonstrated beyond reasonable doubt that the incoming item was indeed a nuclear weapon, and would preferably identify the item as being a weapon of a specific type (e.g. an SS-N-19 or Trident II warhead). However, as we have seen, the UK programme to date has hitherto had a more ‘scaled-down’ objective. Given this, it might be felt desirable to demonstrate that at least the masses of fissile material present before and after dismantling are approximately equal. One constraint on such a demonstration is that the UK takes the view that the NPT precludes the possibility of disclosing the actual masses of individual isotopes to the inspector. It might nevertheless be possible to confirm that the mass of fissile material leaving the facility equals the mass entering, though it is doubtful whether the present state of development of nuclear instrumentation would enable the mass of fissile material to be measured before and after dismantling with sufficient accuracy to do so (see below).

The UK programme has not as yet included work with the more radical objective of confirming that the submitted item is indeed a warhead, or *a fortiori* a warhead of an identified type. As we have seen, the US programme envisaged the possibility of using ‘weapon radiation signatures’ to identify the type of weapon being submitted for dismantling. The idea here is that the host and inspector jointly supervise the gathering of rather extensive γ- or neutron measurements on a sample weapon, under circumstances where the weapon can be identified unambiguously, but those measurements are then encrypted, and this ‘template’ is then stored in a way which will not enable the inspector to read it. The template can then be compared with a similarly encrypted measurement made on a weapon submitted for dismantlement, and the result transmitted through the Information Barrier, confirming whether the submitted item is indeed a weapon of the declared type.

As the world approaches total disarmament, it is likely that the need for complete confidence will become more pressing, and a higher degree of authentication may become necessary.

3.2.2 NPT and national security constraints on the authentication process

The UK programme to date has been based on the assumption that the inspecting party includes someone whose *bona fides* cannot be taken for granted. An initial negotiation is therefore required between the host and the inspection team on what the latter can/cannot be permitted to see and/or measure. In this negotiation, the host has to have regard to the constraints of the NPT, its own national security requirements, and the need to give the inspectors adequate confidence over the whole process. For example, we have seen that in the Trilateral Initiative, the parties agreed that the inspectors might be allowed to receive the results of measurements which confirmed that the item contained U-235 or Pu-239, and that the isotopic composition exceeded some specified threshold. It is then necessary to agree between the two parties on the specification of the 'information barrier' system which will allow the inspector to have reliable access to this, and only this, information. It is assumed that all the relevant equipment will have to be 'host supplied', if only to ensure that it conforms to the host's safety standards applicable to an environment containing nuclear and explosive materials, but the operating procedures have to be agreed, and to be such that both parties can have confidence that it is working as specified.

As was recognised in the early work in the US on verification – particularly in the FT34 project in 1967 and the DOE study in 1996/7 – setting the ground rules for acceptable inspection is a complex business, and involves trade-offs between the potential disclosure of proliferation-sensitive or national-security-sensitive information on the one hand, and providing the necessary degree of confidence that the terms of an arms-control agreement are being observed on the other.

The climate of international opinion on this subject has evidently shifted over the past decades. As we have seen, in the 1967 FT34 project, there was a very high level of concern at the ease with which an unscrupulous host could deceive a highly constrained inspectorate, and it was taken for granted that the rules about disclosure of classified information would have to be relaxed in order to give the inspector a justifiable degree of confidence that the declared dismantling had in fact taken place. Prior to the signature of the NPT in 1968, such disclosures were seen as a matter for negotiation between the parties. Even in 1996/7, the US DOE study seemed to assume that it would be acceptable to negotiate an Agreement for Cooperation between the parties to exchange Restricted Data or 'Formerly Restricted Data', so as to permit an adequately high level of access to the inspector. Certainly in 1989 the Black Sea Experiments seemed to indicate that the Russian government was prepared to contemplate a rather considerable relaxation of the rules governing the use of non-destructive testing (NDT) instrumentation by a foreign national in close proximity to a nuclear weapon.

However by the time of the Trilateral Initiative, the climate had apparently shifted towards a more literal interpretation of the words of the NPT. The IAEA apparently felt obliged to accept rather more stringent restrictions on the information which the host party would supply to its inspectors. This is perhaps not surprising: the period 1986-2006 was one in which international concern about nuclear weapon proliferation grew rapidly, fuelled by problems which came to public attention in India, Iran, Iraq, Israel, Libya, North Korea, Pakistan and elsewhere, and the activities of A. Q. Khan.

So by the date when the UK verification programme began, it was reasonable to assume that the UK at least should be a model of compliance with the strictest interpretation of the requirements of the NPT, and should be equally firm in its control of national-security-sensitive information. The programme has therefore taken for granted that acceptable technology will have to operate behind an Information Barrier, with stringent limitations on the amount of information disclosed to the inspector.

3.2.3 Relevant Non-destructive Testing (NDT) techniques

Most of the UK work has been based on the assumption that the two key NDT instruments to be used in verification work will be a high-resolution γ spectrometer (e.g. of the liquid nitrogen cooled high purity germanium crystal type) and a neutron counter (e.g. of the He-3 type)[9]. The former was selected because it has the highest resolution and the latter because it has the highest sensitivity available. In both cases, it has generally been assumed, for reasons of simplicity, that they will make purely passive measurements, though there would be no difficulty of principle in getting approval for the introduction of a low-power source of high-energy electrons, neutrons or γ-rays into a weapons facility, so that active measurements could be made. However this might be complicated in practice, because of the need to ensure the safety of such systems in a nuclear weapon environment.

As regards γ spectroscopy, a full γ spectrum, taken at a range of one or two metres with a resolution of a few keV, would yield extensive amounts of classified information on the isotopic content of any fissile material contained in the item, on the geometry of the fissile materials present, and (by shifting the spectrometer around) on the composition and thicknesses of various non-fissile materials as well. This information can be inferred even if there is significant interposed shielding material, by making use of the heights of the various peaks and the shape of the background continuum.

As regards neutron counting, the most obvious use is to detect the neutrons emitted spontaneously by weapons-grade U and Pu, at rates of ~1 and ~60,000 neutrons per second per kg of fissile material respectively. The Pu rate is well above the natural background ($\sim 10^{-5}$ n/cm^2/sec) but the U rate is much less so. Further information can be obtained by measuring the time signature of the neutron count, since in a large but sub-critical mass of fissile material, chain reactions lasting up to a millisecond can result from a single initiating spontaneous fission event, and these can be tracked in time, using fast electronics.

Both techniques are relevant to the detection of the isotopes of primary interest, U-235 and Pu-239, but they are also relevant to the detection of other isotopes which are likely to be present in weapons-grade fissile material. These include Am-241, U-232 and Pu-240. Although these may only be present in relatively small amounts, their γ- or neutron-emission signatures can be easier to detect than those of the fissile material itself.

[9] For a good summary of these technologies, see http://en.wikipedia.org/wiki/Gamma_spectroscopy and http://en.wikipedia.org/wiki/Neutron_detection

Both techniques are also relevant to the measurement of the mass of fissile material as a weapon passes through the dismantlement process. AWE recognises the desirability of having a means of tracking this, and is working on this problem, but at present it is unsolved, because of the difficulty of accurately assessing the effect of changing geometry and screening on radiation measurements as dismantling proceeds. Error bars are crucial here. Gamma measurements give a lower bound on the mass, neutrons an upper bound. It is as yet unknown whether active interrogation (e.g. with neutrons) would help: AWE is looking at that, and also at the combined use of more than one experimental technique.

There is a considerable amount of speculative work in progress at AWE on other NDT techniques. For example, it remains open-minded about the possibility of using X-ray backscattering, or dual energy X-ray radiography. It has been tracking this work, but has not yet pursued these techniques in detail.

It is also aware of the academic work in progress on muon-based measurement techniques. This is promising, because it may only reveal non-sensitive information. The AWE verification group is interacting with another group in AWE (National Nuclear Security Division) on this technology. A recent publication gives an indication of the work in progress[10].

A further direction of research being pursued is the use of neutron activation analysis to monitor the presence of high explosives within a container. This technique originated at Idaho National Laboratory, and has been taken up by Dstl (Defence Science & Technology Laboratory) for other purposes. It uses a Portable Isotopic Neutron Spectroscopy System (PINS) – a combination of a portable neutron source (e.g. Cf-252 or a portable 14 MeV D-T neutron generator) which irradiates the container, together with a portable γ spectrometer which determines the proportions of a few light elements (typically H, C, O and N) and hence infers the elemental composition of any explosive present (see, for example[11]). This could permit the verification that the outgoing stream contains fissile material and relevant organic material in separate containers, and hence that 'dismantlement' has been achieved.

3.2.4 NDT experiments on real weapons

Measurements on real weapons have been carried out in the US at least since the 1960s, using the weapons which have been available to them. In addition, as we have seen, some measurements were made on what was presented as a Russian warhead during the Black Sea experiment in 1989. In recent years, the UK programme has likewise made measurements on the weapons to which it has access, including the Polaris and Trident warheads[12]. In general, the results of these experiments have been surprise-free, though they have emphasised the feasibility of extracting classified information from high-resolution γ spectra of a warhead, and the consequent need to use information barrier technology in any exercise undertaken to confirm that the identity of a warhead is as declared, by means of the 'radiation signature' technique.

[10] http://csis.org/images/stories/poni/111007_Cox.pdf

[11] http://www.inl.gov/technicalpublications/Documents/3480146.pdf

[12] A. Burjan & D. Keir, 'Arms Control Verification – Recent studies at AWE', INMM, 48th Annual Meeting, 2007

3.2.5 The need for information barrier technology

There is international agreement (shared by the UK programme team) that the precise isotopic composition, and the geometry, of the fissile core, and associated neutron generators, fission triggers, etc, are highly sensitive items of design information, which would be of substantial value to a proliferator, so all measurements which could reveal these have to be filtered out by the Information Barrier. In particular, as we have seen, a full spectrum from a γ spectrometer reveals much information of a classified nature about the design of a weapon, so some redaction of such measurements is thought to be inescapable.

Given this background, the UK programme has put considerable emphasis on the development of information barrier technology, which will permit relatively uncensored NDT technology to be deployed within the dismantling facility, but only to transmit a redacted version of the information gathered to the inspector. Exactly what data should be transmitted is a matter for negotiation. Since the overall objective is to give the inspector confidence in the dismantling process, it should as a minimum include enough information to convince a reasonably sceptical individual that the item is indeed a weapon, and that the dismantling process does not permit the diversion of any fissile material. It should also preferably give confirmation that the weapon is indeed of the declared type.

A relatively simple application of this technology is to transmit highly redacted information – for example, of the kind agreed between the parties in the Trilateral Initiative (see section 2.4 above). A much more sophisticated application is the use of ‘weapon radiation signatures’ (as described above) to identify the type of weapon being submitted for dismantling. Although this is not yet part of the UK programme, MoD has stated that it would be glad to receive suggestions on how this could be done within the constraints of the NPT.

3.2.6 The need for ‘tamper-resistant’ information barrier technology

One of the overall objectives of verification research is to devise verification technologies and methodologies which can give the inspector sufficient confidence that the host has fulfilled its declared dismantling intentions, or that he can at least verify the host declaration about its activities. It is recognised that there is an inevitable tension between the inspector and the host over the integrity of the verification technologies (including the tools and data involved), because the somewhat byzantine dismantling procedures described above provide opportunities for the host to tamper with the information gathered by the verification instrumentation and transmitted to the inspector, or for the inspector to tamper with the instrumentation to increase its data-gathering capabilities. It is therefore necessary to devise methodologies that disincentivise tampering with the monitoring equipment by either party.

Examples of tampering techniques which might in principle be adopted by the host include inserting an ‘over-ride’ to the response signal to the inspector so that it automatically gives a favourable answer. Likewise, the inspector might wish to increase the information available by improperly inserting sensors which would gather data from within the facility, or electronic means of bypassing the equipment which redacts the information before transmitting it to the inspector.

To minimise the risk of all such activities, there is a need for a ‘certification’ process for all measuring and redacting equipment introduced into the dismantling facility. This equipment needs to be checked by both the host and the inspector in turn for signs of tampering (perhaps using control data agreed by both parties) and to ensure that the function of the device relates exclusively to its role in the verification process (as opposed to espionage activities). The device is then subject to a transparent and robust chain-of-custody process, and returned to the host for use. Details of the certification methodology have to evolve in parallel with possible modes of cheating. Such cheating is potentially very damaging, since it can lead to the instrumentation giving falsely reassuring information to the inspectors.

3.2.7 Work on design and certification of information barriers

AWE has been looking into a number of possible evasion strategies – for example, one involving the addition of large amounts of Pu-238, or one involving the addition of carefully selected non-fissile isotopes which can mimic fissile material to some extent. Counter-measures can be based on the fact that such additions cannot mimic both the energy spectrum and the half-life.

It is also working on measures to protect against tampering with the built-in software in the information-barrier system. Because of the intrinsic complexity of the software, detection of malfeasance can be difficult. The current approach is to keep the software simple and bespoke, written in a checkable language and then written into a chip. It has to be open to both the host and inspector. AWE is in favour of joint development of software, preferably software which is mathematically provable (e.g. using ADA).

It has been suggested that even if the full gamma spectrum cannot be made available to the inspectors, some parts of the spectrum might be – for example the 185.7 keV gamma line of U-235, the 1001 keV line of Pa-234m (first daughter of U238), 51.6 keV, 129 keV lines and/or 630-670 keV region of Pu-239. The AWE view is that possibly some regions might be made available, but certainly not the region 630-670 KeV, which contains all the Pu isotopics information. Probably any region which would be useful to the inspectors would be too sensitive: "If it's useful, it's too sensitive to give away."

More generally, since the methodology has to be unclassified, and agreed between the host and the inspector, there is a need to develop algorithm(s) to be used and to agree the outputs to be transmitted.

A rather unusual approach to the construction of an Information Barrier has been developed in a project undertaken by AWE jointly with Aberdeen University, based on the concept that an artificial neural network could be used as a means of implementing the concept of a trusted Information Barrier for measurements made with a γ spectrometer[13].

3.3 UK work on chain of custody

The dismantlement process can be regarded as beginning when a box containing the weapon is presented at the door of the dismantlement facility, and ends when at least the fissile components are posted out of a disposition facility in a form suitable for dispatch to a reactor fuel fabrication facility or to a long-term monitored store for civil fissile material.

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[13] O. Aitkenhead & J. Chambers, 'Use of artificial neural networks in measuring characteristics of shielded plutonium for arms control', *Anal. At. Spectrum*, 2012, 27: 432 www.rsc.org/jaas

The process may take weeks or months to complete, and the ‘chain of custody’ is the set of procedures that ensure that, during the entire process, the identity of the weapon and its components remains uniquely defined (so as to permit the maintenance of an accurate inventory of weapons which have been dismantled), and that no fissile material is diverted, and no extraneous nuclear materials are introduced which could mislead the verification instrumentation. The feature which complicates the design of the chain-of-custody procedure is the same as that which complicates authentication – the inspector is not allowed to have direct (or even remote visual) access to the weapon or its components during the dismantling process, and can only have restricted access to instruments used to monitor the chain of custody. The key tools are tagging, sealing and ‘tamper-indicating enclosures’.

3.3.1 Tagging of incoming and outgoing items
Tagging is the means whereby the identity of the weapon is preserved as dismantling proceeds. Each incoming item is given a unique identifying tag, which stays with it until it enters the dismantling cell, so that there is no scope for ‘recycling’ incoming items and so falsifying the number of items dismantled. No attempt is made to maintain ‘continuity of tags’ through the dismantling process. (During that time, diversion or evasion techniques are discouraged by monitoring of entrances and exits to the cell, and by radiation searches before and after its use). However only one weapon enters the dismantling facility at a time, and the outcoming containers are also tagged uniquely, so that their tags can be correlated with the tag on the incoming weapon (tags are never transferred). The instrumentation used to monitor the tagging process has to comply with the host's safety regulations, so it has to be ‘host-supplied’, but the inspector has to be satisfied that no deceptions have been introduced. Equally, the host has to be satisfied that the instrumentation does not incorporate any covert capability.

Possible malpractice includes the use of simulated tags. All commercially supplied tags are thought to be capable of replication by a skilful counterfeiter, so one current AWE approach is to use absolutely unique tags based on random patterns. The challenge in ‘random pattern’ tagging is to develop a computerised technique for comparing images of a tag before and after a period without direct observation, to confirm that it is the same tag. AWE’s recent experiments have indicated that comparison of patterns by eye works better than computer comparisons, because, for example, the computer can be confused by changing light levels in the facility. AWE also wants to use the same ‘pattern recognition’ technique to tell whether two successive photographs of a facility taken from the same position show that the facility has been altered. Work outside AWE on accurate change-detection software is being monitored.

3.3.2 Sealing and the use of Tamper-indicating Enclosures
Sealing is the means whereby the inspector can be assured that the contents of a container or facility remain unaltered during a period in which it is not subject to direct observation. This is clearly not applicable to the weapon itself while it is within the dismantling facility; however it can be applied to doors in and out of the facility and to any containers involved prior to entry or after exit from the facility. The design of such seals, and of the instruments used to detect any attempt to break them or tamper with them, is a complex matter (see footnote[8]). Sealed containers may need to preserve their sealed integrity over long period of time, if the contents are to be held in monitored interim storage until a disposition facility becomes available. In general, seals need to be tagged, since one potential evasion strategy is the complete replacement of a seal.

Tamper-indicating enclosures are units which have been designed to indicate to the inspector that the host has attempted to access their interior during a period when it was not subject to direct observation. Optical fibres are currently seen as a key element in one possible implementation of this concept. The proposed approach is to embed in the structure of a plastic or fabric enclosure a network of optical fibres linked to a single collection point. Any attempt to breach the enclosure (even if there were a subsequent attempt to repair the entry) would be likely to lead to a change in the signal of transmitted light; various techniques could be used to interrogate this signal. AWE recently started work on this approach, and although it looks promising, they are not yet clear that they have found the best way to use optical fibres, or that this is the best way of doing the job[14].

AWE has reviewed the work at IAEA on sealing and tagging techniques, but they are not sure that this is always immediately applicable: most of the recent IAEA work is too complex for the dismantlement environment. One problem is that in the dismantlement context, the chosen technology has to be acceptable to the host. However AWE is collaborating with US colleagues who have done work on the ideas/systems being developed by IAEA.

4. UK programme: plans for future work

MoD is in the process of preparing a written statement on the objectives which it aims to meet by 2015, and on its future work programme beyond 2015. We understand that the intention is to present this within the current NPT review cycle. British Pugwash has not yet seen such a statement, but has made some suggestions relating to this in the following sections. As regards the longer-term future programme, we would like to make the following observation.

4.1 The possible need for a dedicated dismantling facility in the UK

The UK, like a number of other potential host countries, does not currently possess a purpose-built facility dedicated exclusively to the dismantling of nuclear weapons. At present, the only facilities which it has available for dismantling operations are located within its existing nuclear weapons complex, in which the buildings are not specifically designed for intrusive verification operations, and are still being used for legitimate nuclear warhead work. However AWE is currently in the process of constructing a new facility at Burghfield known as MENSA for the final assembly and for the dismantlement of Trident warheads, and the verification team has been able to make an input into the design of this facility to assist verified dismantlement. However this input has been limited, and based only on accumulated verification knowledge to date, which is far from complete. Nevertheless, experience from the MENSA project should be able to inform possible future consideration of a dedicated dismantlement facility, at a time when three broad options might be to: (a) use an existing facility; (b) modify an existing facility; or (c) construct a purpose-built facility.

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[14] H. White, P. Wynn, K. Allen et al, ‘TIEs with optical fibre’, INMM, 50th Annual Meeting, 2009

5. British Pugwash comments on the UK programme to date

In offering our comments on the AWE verification programme, we are aware that we are able to comment only on the basis of the information made available to us during the review process, having regard to the level of security clearance that the team was given. As indicated in section 1, information was made available orally by MoD/AWE, with discussions ensuing, at both an unclassified workshop and two classified briefings, plus a further classified discussion at which a number of specific issues were raised and discussed. In addition, our attention was drawn to a number of published papers, and one further restricted paper was made available by AWE.

We did not have access to internal reports on the experimental work at AWE, so we are unable to comment on the technical robustness of that work. It was also indicated to us that some relevant information was generated within the framework of the UK-Norwegian programme, but was not presented to us because that lay outside the agreed scope of this review. In some discussions, some of the queries raised by the team could not be responded to in depth, as our clearance level was insufficient to allow a full response. Consequently, we are aware that some of our comments and recommendations could be affected by these considerations. Although we think we are in a position to comment sensibly on a range of issues of interest to MoD/AWE, we suspect that a rigorous review would require a higher level of clearance to access information and enable effective discussion on a number of relevant issues. Our comments should therefore be considered in this light.

The British Pugwash team has structured its thoughts on the UK programme by seeking to answer the following questions:

1. Is the current UK programme correctly focused?
2. Are its conclusions about the appropriate technologies correct, and are there other potentially useful technologies or methodologies that may not have been explored?
3. What problems has the programme already solved?
4. Is that level of achievement commensurate with resources used?
5. What problems remain to be addressed?
6. Is the MoD team rightly structured for the tasks ahead?
7. Is there a need for involvement of other UK resources?
8. Do security clearance issues affect collaboration: if so, then what?
9. What is the right timescale for this work, and what funding is required to achieve that timescale?
10. What reporting, publishing and literature scanning activity is required?

5.1 Is the current UK programme correctly focused?

We think that the MoD programme is appropriately focused, given the political guidelines within which it has been defined. However we suspect that those guidelines may change over the next few years because:

- In the short term, the main focus will be on verification of bilateral agreements which lead to no more than a partial reduction in large weapon inventories. Because of this, there may not be a need for a very high level of confidence in perfect compliance with the treaty provisions, and there is considerable scope for 'private agreements' between host and inspector – for example, on sharing of 'weapon signature' information.

- In the longer term, there may be a willingness among some countries with small inventories (say < 200 weapons) to disarm completely. In this case, the security concerns of the host country change their character, but the inspectors need to ensure that the neighbouring states have a very high level of confidence in the completeness of the host's disarmament.

- In the very long term, the emphasis will hopefully shift to 'getting to zero' globally. In this case, verification will have to cover not only the dismantling of all existing weapons, but also the decommissioning of all facilities which could be used in a 'nuclear breakout'.

All of the above changes in emphasis might lead to an internationally-endorsed relaxation in the current UK insistence on zero disclosure of classified information, and an acceptance of a shift towards more intrusive inspection.

We think that the UK could take a lead here, for example, by proposing a set of minimum relaxations of its existing national security guidelines which would give the international community confidence that the verification process has confirmed all the declarations made by the host. This would clearly involve discussions between MoD and Ministers on the balance between the security risks and the confidence benefits involved.

5.2 Are its conclusions about the appropriate technologies correct?

Given the present dismantlement verification guidelines, which preclude visual inspection of the dismantling process, and impose severe constraints on the information which can be passed through an Information Barrier, the emphasis has to be on the design of the Information Barrier and on chain-of-custody technology, and the main objective has to be the prevention of evasive malpractice. The UK programme is correctly focused on these, but there are some further issues to be considered which could provide appropriate opportunities for future work.

- There is not yet an agreed methodology for ensuring that host declarations about the type of weapon submitted are correct.

- There is not yet a method for verifying that the mass of fissile material remains unchanged during dismantling, except by taking steps to ensure that there is no obvious channel through which it could have been diverted.

- The design of the information barrier technology has so far focused on Information Barriers with 'yes/no' outputs: there needs to be further study of more complex outputs – for example, those relating to 'weapon signature' templates.

- The AWE team has so far focused on two key NDT devices – the high resolution germanium γ spectrometer and the He-3 tube neutron counter. This is a plausible decision, but in view of the much wider range of NDT technology now on the market or in the laboratories of academia, it is not obvious that these will remain the best choice (either in effectiveness or cost terms). Simultaneous use of different detection technologies for assessing special nuclear materials may be advantageous in light of severe information barrier constraints.

- Because of restrictions in the scope of the current programme, the MoD/AWE teams have not yet explored the possibility of undertaking more 'denaturing' activities (e.g. shredding) within the dismantlement cell, so that the emerging fissile material has been stripped of at least some of its classified attributes, and so could be subject to a more intrusive authentication programme after exit but before it is posted into the disposition facility. Such a step would also make it more difficult to 'recycle' fissile cores. We recognise that the level of security clearance we were given may prevent us from assessing the possible difficulties (e.g. health and safety issues) of such an approach. Nevertheless the balance between NPT/security constraints and international confidence in the verification process should be quantified for this scenario.

- The science and technology employed in the programme is broad-ranging and covers a range of traditional disciplines. This makes it particularly challenging for a small team to keep abreast of related work going on elsewhere (either in or outside academia). From our limited exposure to the work programme, we suspect that there are some areas where experience elsewhere can be brought in to help solve some of the technical problems identified to us. Making effective contact with the external scientific community on matters of potential interest to the verification programme, and 'horizon scanning' for useful developments made elsewhere, is not easy and can be resource intensive. However, MoD has taken significant steps elsewhere to address both of these challenges (for example, the Centre for Defence Enterprise and the horizon- scanning operation at Dstl respectively).

- The programme has not as yet given much attention to the role which social scientists could play in devising means of engendering trust in the dismantlement process. There may perhaps be a need to clarify the level of confidence required in advance of any particular disarmament negotiation. We know that MoD is aware of this and we would encourage further involvement with appropriate experts.

- There may be a need for public education on the verification process, particularly aimed at non-nuclear weapon states, which may regard the complexity and cost implications of the dismantlement process and its verification as a form of obfuscation and a delaying tactic promoted by the P5 states. In doing so, there may be a need to revisit the assumptions which are currently being made about the constraints under which the verification of dismantlement process must be undertaken. There may also be value in inviting the P5 to consider what information really is proliferation-sensitive.

5.3 What problems has the programme already solved?

The programme has made very good progress in defining the operational flowsheet for a possible verified dismantlement facility. The concept of a closed dismantlement cell, to which the inspector has very limited 'managed access', but with effective portal monitoring of all exits and entrances, is rather convincing. The arrangements for tagging, sealing and monitoring of outcoming containers, and the transition from that regime to the 'disposition facility' have not yet been defined in comparable detail. The programme has also ensured that AWE personnel are now well acquainted with the NDT technology that they have chosen.

5.4 Is that level of achievement commensurate with resources used?

Given that the programme has now been under way for over 10 years (albeit with rather limited resources available to this part of the programme during the first seven years), it is perhaps disappointing that the list of published achievements is not greater.

5.5 What problems remain to be addressed?

We have noted (in para 3.2.5 above) that the use of 'weapon radiation signatures' to identify the type of weapon being submitted for dismantling is not yet part of the UK programme, but that MoD has indicated that it would be glad to receive suggestions on how this could be done within the constraints of the NPT.

We have also noted (in para 5.2 above) that there are some other lines of investigation which have not yet formed part of the UK programme, but which we judge to merit further consideration.

Looking further ahead, there is a more substantial but potentially extremely valuable task which can be envisaged – to design and construct a new dismantling facility, or a dedicated area within an existing facility in AWE, and to demonstrate its operation on a full scale with real weapons, and with observation by an independent inspectorate.

5.6 Is the MoD team rightly structured for the tasks ahead?

Although AWE undoubtedly has staff with the right background and experience to design, construct and operate a full-scale facility, the existing verification team has a relatively academic outlook, and could very usefully be reinforced by staff with more operational experience, if it is to have the right resources to meet the longer-term challenge.

5.7 Is there a need for involvement of other UK resources?

British Pugwash has for some years argued that if the UK is to play the role envisaged by Margaret Beckett – to be a "disarmament laboratory for the world" – it needs to institutionalise that role. One obvious way to do this would be to create an organisation focused on nuclear disarmament. Its status would be analogous to SIPRI – i.e. British, but with the participation of international experts. The verification mission is one, but only one, of the missions which such an institution could undertake (for a broader view of its overall mission, see[15]). In our view AWE could play an important role in such an organisation, but it would be essential to involve UK academia and NGOs with expertise which complements that at AWE. We are aware of AWE's two recent University collaborations in this area – with Heriot Watt (on pattern recognition using Bayesian techniques) and with Aberdeen (on neural network techniques) – but apparently there are no other current collaborations, though there are discussions with a number of individual academics. We think that it would

[15] Rotblat centenary celebration, held at the Royal Society, 10 December 2008
http://www.britishpugwash.org/Rotblat%20Centenary%20Dec%2010.htm

be valuable to strengthen the programme in this respect (see also the sixth bullet of section 5.2 above). We are also aware of the UK's collaboration with the US verification programme, both with the Obama administration and with the Carnegie Institute, which is running a series of workshops on verification. We believe that a UK disarmament institution could be a means of encouraging (and effectively contributing towards) such international collaboration.

5.8 Do security clearance issues affect collaboration: if so, then what?

Unfortunately they do. This ‘peer review’ exercise has highlighted a number of problems in this area. It took several months to get security clearance for the BPG team, and even then, the level of clearance was such that we were not able to address many technical questions at the right level of detail (this problem was highlighted in the questions that we raised at our meeting on 27 May 2011). We recognise that this audit exercise has already broken new ground in this area, and we are very glad to have participated. However in the longer term, as commented in the opening two paragraphs of section 5, we believe that really effective peer review, or other collaborative exercises, would require a higher level clearance. Interestingly the US JASON procedure largely gets round this problem in their system. The UK Blackett process, which was at least partly modeled on the JASON mechanism, may be able to play a part here. However, the cost (in cash and time) of the higher level of clearance required for effective cooperation is likely to act as a barrier. In the short term these costs may appear high, but when the prize is an effective and robust nuclear weapon dismantlement verification system, the costs would surely be more than worthwhile.

5.9 What reporting, publishing and literature scanning activity is required?

The UK programme has been reported in broad outline at the NPT review conferences and PrepComs, and at a few international meetings (for example, of the Institute of Nuclear Materials Management (INMM) and the Safeguards Agency). However we were disappointed to learn that there are rather few reports of a more technical nature on the programme, and the few that exist are too highly classified for us to have sight of them. It seems to us that even a programme which has limited resources should produce both regular internal reports and a flow of open publications in the literature. As noted above, the limited information made available to us has made it difficult for us to audit the programme at the level of technical detail that we think is necessary for such a review to be really useful. More open publication would provide good publicity for the UK initiative in this field, and would also allow more effective peer review of the programme.

In our view, this internal reporting and publishing activity should be accompanied by a science and technology scanning activity, to ensure that the UK programme remains fully abreast of the international work in this field. We are aware that AWE has a ‘horizon scanning’ service, which has been asked to make specific scans relating to verification technology. We recognise that effective horizon scanning is not trivial – especially in situations such as this, where work which might be of interest could easily originate in a field which is remote from the ones that would naturally be scanned, and hence not easily picked up. Broad vision and breadth of knowledge is crucial if such horizon-scanning exercises are to be really effective. See also our comments in section 5.2.

5.10 What is the right timescale for this work, and what funding is required to achieve that timescale?

The rate of progress of the work to date will need to be ramped up if it is to meet the challenge of a foreseeable acceleration of the international nuclear disarmament agenda. Additional resources will be required to make this possible. It would also seem to us appropriate for the UK to set itself a deadline to produce a rather substantial report on this field in time for the 2015 NPT review, and to consider seriously whether to propose the construction of a dedicated dismantlement facility shortly thereafter.

6. Audit team suggestions for future work

6.1 We believe it would be valuable if the MoD/AWE team put in writing a programme of work with milestones at 2015 and 2020. Ideally, such a programme should be specified in functional terms, rather than in terms of the technical solutions, and it should not be excessively constrained by the resources currently available, which we judge to be seriously insufficient. It should be based on a flow-sheet for the whole verification process, starting with the weapons located in some military facility, and ending with materials fully stripped of any residual classified information and hence available for civilian use. It should include a range of possible scenarios for the use of the verification system, taking account of the likely or possible developments on the international disarmament scene. It should make realistic assumptions about the composition of the inspecting team, and should set out the non-proliferation constraints within which the verification system should be constructed. These should be specified in such a way as to create a reasonable balance between the risk of proliferation, and the benefits flowing from a successful disarmament programme in which the international community has confidence in the outcome. It should also specify the steps which need to be taken in order to ensure that legitimate weapons-related activities in the dismantling facility are not completely disrupted by problems over weapon security, NPT regime, health and safety, material control and accounting, and legal requirements.

6.2 We believe that it would be valuable if MoD set a timetable for its contributions to the 2015 NPT review, including headings for papers to be submitted to the PrepCom, and ensures that these are consistent with the programme of work specified under 6.1. In our view it would be helpful if the contributions included specific proposals on ways to achieve the right balance between non-proliferation and international confidence in the verification process.

6.3 We hope that MoD and AWE will be willing to work with British Pugwash to explore its vision of a Disarmament Institute along the lines set out in 5.7 above.

6.4 We hope that MoD will continue to encourage experts from Universities and NGOs in the UK and overseas to work with it on solving problems in the verification field, and that it will find ways of overcoming the barriers to such collaboration created by security issues (perhaps along the lines of the US JASON scheme and/or expanding the Blackett process). It would be valuable if it could develop a framework for such collaboration, if possible including an appropriate level of international collaboration. Again we would point to the success of MoD's Centre for Defence Enterprise in encouraging collaborative development with (largely but not exclusively) industry, and the well-developed horizon scanning operation at Dstl.

6.5 We hope that AWE will institute a system of preparing technical papers on its work with the level of academic rigour which is normal in government-funded academic R&D programmes, and that wherever possible unclassified versions of such papers will be published. This would enhance the reputation of the UK as a leader in this field, and would contribute to a public awareness of the complexity and importance of the subject.

Annex 1

The following British Pugwashites participated in meetings and workshops during 2011-2012 at which MoD and AWE staff made presentations on the UK programme:

1. Workshop held at UCL on 10 March 2011:
   Gen. Sir Hugh Beach
   Prof. John Finney
   Carol Naughton
   Dr Nick Ritchie
   Prof. Ruben Saakyan
   Prof. John Simpson
   Dr Christopher Watson

2. Briefing for security-cleared members of the British Pugwash team at Aldermaston on 4 April 2011:
   Mr Brian Anderson
   Gen. Sir Hugh Beach
   Prof. John Finney
   Dr Christopher Watson

3. Discussion of the team's questions with MoD and AWE staff at a meeting in London on 27 May 2011:
   Prof. John Finney
   Dr Christopher Watson

4. Briefing for recently security-cleared members of the British Pugwash team at MoD on 24 November 2011:
   Dr Nick Ritchie
   Prof. Ruben Saakyan

5. Discussion on finalisation of the British Pugwash audit report at MoD on 16 March 2012:
   Prof. John Finney
   Dr Christopher Watson

The present peer review report has been agreed by:

Mr Brian Anderson
Gen. Sir Hugh Beach
Prof. John Finney
Dr Nick Ritchie
Prof. Ruben Saakyan
Dr Christopher Watson

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