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**Verification of nuclear disarmament: second interim report
on studies into the verification of nuclear warheads and
their components**

**Working paper submitted by the United Kingdom of Great Britain
and Northern Ireland**

Summary

The United Kingdom announced [1] at the 2000 NPT Review Conference that it had just commenced a programme to consider techniques that could be used in the multilateral verification of any future arrangement seeking to control, reduce and ultimately eliminate stockpiles of nuclear weapons. This paper describes the work in progress that the United Kingdom is conducting on the verification technologies that may be considered for use during the dismantling of nuclear warheads into their component parts for disposition of the various materials arising from the process. Several technologies that could aid the verification process have been explored and some progress has been made. Further work on most of these technologies is still needed. One conclusion already drawn is that to permit members of an international inspectorate to verify unequivocally the dismantling process without compromising sensitive nuclear warhead design information has many challenges.

INTRODUCTION

1. At the 2000 Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons the United Kingdom announced [1] that it had recently commenced a programme to consider technologies that could be used in the multilateral verification of any future arrangement to reduce and ultimately eliminate stockpiles of nuclear weapons. There will no doubt be intermediate and transitional phases towards nuclear disarmament that will depend to a large extent on the outcome of future arms control and treaty negotiations. It is not the purpose of this paper to speculate on what these may be but to concentrate instead on methodologies to aid any future disarmament treaties.

2. The UK identified three main areas of work (see Figure 1) within its programme focussing on:
 - the authentication of warheads and their components, namely establishing that an item declared to be a nuclear warhead or a component from a nuclear warhead is consistent with those declarations;
 - the dismantlement of warheads and their components; and
 - the disposition of fissile material and other components arising to ensure that they can no longer be used in nuclear weapons or other nuclear explosive devices and can be irreversibly disposed of.
3. In addition the United Kingdom also considers the monitoring of the environment in the vicinity of nuclear weapon complexes as a potentially important adjunct to warhead measurements that could be useful to the verification process.
4. This work has been conducted in part as a UK contribution to "the further development of the verification capabilities that will be required to provide assurance of compliance with nuclear disarmament agreements", which is the 'thirteenth step' on nuclear disarmament referred to in the Final Document agreed at the NPT Review Conference in 2000.
5. At the second session of the Preparatory Committee for the 2005 Nuclear Non-Proliferation Treaty Review Conference held in Geneva in 2003 the United Kingdom submitted an interim first report as a working paper [2] on this programme of work. That paper concentrated principally on the authentication of items presented as nuclear warheads or as components. This current paper focuses on the dismantlement of nuclear warheads and their components. It describes the experience within the United Kingdom's defence nuclear programmes of a number of techniques that could be relevant to the warhead dismantlement process. However, in pursuing this work the United Kingdom recognises that there exists already elsewhere a wealth of experience on many potentially applicable techniques. [3-4]. These are to be found not only within the civil nuclear safeguards community and civil nuclear facilities but also in work associated with the Trilateral Initiative involving the United States, the Russian Federation and the International Atomic Energy Agency (IAEA). The United Kingdom is drawing on these where appropriate for this particular study, which we believe is the first occasion they have been considered in a nuclear warhead operational environment.

THE DISMANTLEMENT PROCESS

6. The exact details of the process for dismantling any particular warhead will be specific to that warhead. However, some processes are likely to be generic (see Figure 2) such as:
 - transporting the assembled warhead to a dismantlement facility;
 - disassembling the warhead into its main components: for example, removing the physics package (i.e. the heart of a nuclear warhead) from its casing or re-entry body casing and other major sub-assemblies such as the Arming, Fusing and Firing systems;

- disassembling the main components into sub-components: for example, breaking down the physics package into primary and secondary components and further sub-division, for example breaking down the primary into the fissile material, non-fissile materials and the high explosive supercharge;
 - when and where appropriate, storing the resulting materials and components prior to the final disposition;
 - demilitarising (i.e. denying re-use) and declassifying (destroying classified design information) on specific warhead components by, for example, shape destruction or burning.
7. Any verification of many of these processes will be challenging, given that there is the need to protect, *inter alia*, warhead design and security information both for non-proliferation and national security reasons. But the key requirement would be to provide confidence that the outputs at the end of the dismantlement process had indeed come from the items declared to be, and authenticated as, nuclear weapons at the start of the dismantlement process. Crucial to achieving this 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.
8. The United Kingdom began this study by considering whether any of the existing approaches used elsewhere might be adopted for the specific dismantlement processes being considered in the verification of warhead reductions, dismantlement and disposition. Some potentially suitable approaches have been investigated further through practical work.

CHAIN-OF-CUSTODY

9. Ensuring a chain-of-custody while an item is being moved through various stages in a process or facility requires the use of appropriate technological means to maintain control over the stated condition of the warhead, its components and sub-components - i.e. to ensure no diversion. Various approaches to maintaining a chain-of-custody have been used extensively by the International Atomic Energy Agency (IAEA) [5], in the course of its implementation of the international safeguards regime, and by Euratom safeguards. The United Kingdom already applies some of these at its atomic weapons establishments for both fissile material movement control and safety purposes. These are, of course, carried out for national purposes, but the question is whether there are means by which they can be used by an external body for verification.
10. For the purposes of this paper "chain-of-custody" is defined as :
- "the act of maintaining control over the stated condition of a warhead and its components through the dismantlement and disposition process from the point of entry to the point of exit of the controlled items."*
11. The technological possibilities for such external verifications include, *inter alia*:
- Tags and Seals

- Remote monitoring
- Item tracking
- Portal monitoring.

Tags and seals

12. These means are not new and have been used extensively amongst the safeguards measures applied by the International Atomic Energy Agency and also by the European Commission under the Euratom Treaty. The United Kingdom already uses tags and seals to ensure that a warhead received at its disassembly facility is that which has been removed from the warhead stockpile. However, the level of integrity in the situation may be different to that required in a multilateral treaty environment. The United Kingdom has conducted studies looking at potential roles for tags and seals for inspection equipment authentication as well as chain-of-custody maintenance during transport, storage and dismantlement of the warhead.

Remote monitoring

13. Remote monitoring, such as Closed-Circuit-Television (CCTV), has also been extensively used in production and other warhead facilities, mainly for Material Control and Accountancy (MCA) purposes. Images from CCTV cameras are generally displayed at other locations within the facility concerned. However, it may be acceptable, as in the case of security cameras in public areas, to relay the images to some central location such as an international verification centre, provided it can be ensured that no sensitive warhead design, security or proliferation information is also transmitted. This also is an application that has been the subject of much development and increasingly routine implementation in the context of international safeguards application.
14. As described in the paper [2] presented at the 2003 Preparatory Committee meeting, nuclear warheads and components emit various nuclear and other radiation. Some of these radiation outputs can be used to track movements within and also in and out of disassembly facilities and therefore may have some role in the remote verification of the overall decommissioning and dismantling process.

Item tracking

15. Item tracking, i.e. following the passage of any item through a facility using hand written accompanying record cards, has been used extensively in the past during the movement of nuclear warheads and for some of their components. This procedure requires signature as an item is passed from one custodian to another. With the advent, during the last two decades or so, of bar-coding and computer recording of information (i.e. bar-code reading), the system has been computerised, but nevertheless the same principles of maintaining a system of custody and transfer of custody of the item apply. Verification of such records, their transmission to a central external location, again, such as an international verification centre, offers some possibilities in verification.

Portal monitoring

16. In nuclear facilities portal monitors aid the control of the flow of fissile material into and out of specific areas such as rooms or buildings, and also serve to isolate such an area from the surrounding environment. These ensure no unauthorised removal of materials out of facilities without detection. Such detectors are used, where appropriate, at many facilities at the United Kingdom's Atomic Weapons Establishment in order to detect any unauthorised movements of fissile materials. These monitors have tended to be linked with building or facility security systems, but again it is possible, provided that any security concerns are managed, that their outputs could be relayed to a central verification centre external to the establishment.
17. A major concern with several of these chain-of-custody technologies is their vulnerability to tampering. CCTV images need to be authenticated and tags and seals need to be able to demonstrate evidence of tampering. This is recognised as an area which has been the subject of much attention in the context of international safeguards and the United Kingdom is beginning to conduct studies looking at potential roles for the above technologies within any future multilateral nuclear warhead reduction arrangement or treaty. Although the work is based on practical experience, it would be incorrect to conclude, at this stage, that the systems already in place at the United Kingdom's Atomic Weapons Establishment would be consistent with the requirements of an inspection regime in respect of any treaty obligation; the systems were not installed for that purpose.

INSPECTION TECHNIQUES

18. There are also a number of ways in which the dismantlement of a nuclear warhead might be verified by both non-visual and visual access means. Those that do not necessarily require direct visual access by inspectors and which, for security reasons, may need to be behind 'information barriers' include:
 - Sampling and analysis of warhead materials. These need not necessarily be fissile materials but could include structural and other inert materials. For some materials this can lead to an estimated age since manufacture. Comparison of this estimated age with the declared age of the warhead can aid confidence in the overall process of verification of nuclear warhead reductions;
 - Comparison of various non-destructive analysis images from warheads. For example, the gamma-ray spectra and radiographic images of a declared warhead [2] may be compared with that of a known specific type of warhead, i.e. a "template". This could also contribute to the chain of custody since it is possible that a spectrum "fingerprints" a warhead type;
 - Verification of the accountancy records for materials concerned, especially fissile material, within a given defined location such as a glove-box or room, i.e. measuring (by weighing) the transfer of fissile material in, through and out of defined facilities;
 - Environmental monitoring of gaseous or particulate emissions in the vicinity of the warhead during its dismantlement;

- Examination of paper and computer records generated during the dismantlement process.

Non-destructive analysis

19. United Kingdom disassembly studies conducted to date include exposing a metal foil to the neutron flux from a plutonium component. This demonstrated that the foil was activated after a suitable period of time. Neutron activation of structural and other materials could theoretically enable the age of the warhead to be established, although the accuracy of dating would depend on the statistics of radioactive counting. This could also help to establish the identity of certain non-nuclear warhead components, thus aiding the process of authenticating that the age of the item concerned is consistent with any declaration. This is an important early step in the overall process of dismantlement and disposition. Although neutron activation of metal foils is not new, we believe that the approach has not been studied to any significant extent in the context of nuclear warhead verification. Nevertheless, its trialling in an operational environment and proof-of-principle contributes to the United Kingdom's understanding and information base on potentially applicable technologies.
20. "Before" and "after" templates, derived from non-destructive assay measurements such as gamma ray spectra and radiographic images can be compared to determine that components have come from a declared source. Comparison of neutron time-correlated templates for some warheads and components has been carried out by the United Kingdom and it has been shown that the template is unique to a specific type of warhead or component. However, there may be some variability in the exact details of specific items within each class of warhead or component, and 'information barriers' may need to be applied. The inter-comparison technique for templates has been demonstrated using both high and low resolution gamma ray spectroscopy on two nuclear warhead pits (i.e. the main sub-component containing fissile material) of the same type and a third of a different type. Within the statistical limits of radioactive counting, the first two pits had identical signatures but differed from the third. Such determinations may not alone provide unequivocal proof that the item is exactly what it is declared to be but, when taken in conjunction with other information, can form a useful part of the overall process of verification.

Material Control and Accountancy (MCA)

21. Material Control and Accountancy is an approach that has been used for decades in the nuclear industry in managing criticality safety and accounting for fissile material as it passes through a number of stages or processes (often termed Material Balance Areas) within nuclear facilities. It is also a fundamental component of the international safeguards regime applied to civil nuclear materials. Such application requires the definition of areas (Materials Balance Areas) and their boundaries and the recording of the mass of fissile material crossing these boundaries. Such an approach, again coupled with other approaches described in this paper, could prove useful in verifying a dismantlement process.

Environmental Monitoring

22. During warhead disassembly, characteristic gaseous or particulate emissions might occur that could be detected by a number of means, for example, chemical or radiometric. During the dismantlement of the United Kingdom's Chevaline warhead, air-sampling measurements were made in the building atmospheres and smears were taken from containers and the warheads themselves. Materials identified during this part of our work were consistent with the materials known to be used in this warhead. The levels detected were of no health or safety concerns. However, the fact that they were detected demonstrates that even with good containment practices, materials can be found external to the fissile material containment volumes - in this case, glove-boxes. The detection of such emissions could give some confidence to the declaration that a nuclear warhead is being disassembled. However, such techniques assume certain materials are being used, but not all states with nuclear weapons will necessarily employ the same technologies in the design and manufacture of their nuclear warheads.

Recording of information

23. Records of information can be kept either on paper or on computers, or a combination of both. The first is well established and has been used extensively, but increasingly modern practice is to move towards computerised systems. An increase in reliance on computer and paper systems raises the risk of information being deliberately created or removed, as these systems are self-administrated. Unprotected computer records are potentially more vulnerable to alteration than comparable paper records. Therefore, appropriate computer or procedural controls are necessary to prevent unauthorised tampering. This could require an independent authority that would need to establish administrative controls that are transparent to third party audit.
24. Within a nuclear warhead disassembly facility the recording of information is used for process control or safety purposes. However, such recording could be of value as part of the verification process. The United Kingdom's system for process control during disassembly requires authorisation by responsible personnel at each stage of the overall process. This practice has served the United Kingdom well for decades and is now being computerised. This new system has the advantage of being able to access and store information relevant to the warhead disassembly process in a more timely and effective manner.
25. An alternative approach could be to use encryption technology to control and authenticate records. In this case, falsification is likely to be difficult. The United Kingdom has only just begun to explore this approach and further study is necessary before any firm conclusions can be drawn.
26. A summary of inspection techniques that do not necessarily require direct or visual access is given in Table 1.

INSPECTIONS THAT REQUIRE MORE DIRECT VISUAL ACCESS

27. By their very nature, direct visual inspections of a warhead dismantlement process will be intrusive, in that inspectors will most probably require close visual access to the warhead and some of its most sensitive components and sub-components. It would therefore be necessary to consider very carefully whether it is possible to accept the resulting risks, which may involve compromising sensitive information, in order to provide the inspectors with more confidence that the dismantlement process has occurred. A risk/benefit analysis will need to be undertaken for each individual case, given that a generic solution for every scenario is unlikely. In addition, some negotiation at the time of an inspection is likely to be required.
28. Nuclear material assigned to meet defence requirements is not subject to safeguards inspection by Euratom or the International Atomic Energy Agency. Nevertheless, the United Kingdom has limited experience of various types of inspections at sensitive nuclear warhead facilities and has three sources of experience to draw on in assessing the scope for visual inspections. These are:
 - routine inspections by UK regulators, for example the Nuclear Installations Inspectorate (NII), whose staff are UK nationals but are external to the nuclear or defence industries;
 - exercises by UK personnel conducting simulation challenge inspections that could occur under the Chemical Weapon Convention (CWC): i.e. the UK "practice challenge inspections", of which several have been carried out;
 - an exercise carried out as part of this study that involved personnel notionally not possessing appropriate security clearances acting as inspectors under a verification regime. The exercise was related specifically to assessing the scope for and extent of visual inspections of the nuclear warhead assembly/disassembly facility.

Inspections by UK Regulators

29. For many years the Atomic Weapons Establishment was completely exempt from domestic regulation by the Nuclear Installations Inspectorate, the body that regulates the United Kingdom's civil nuclear facilities. However, in the late 1990's the Atomic Weapons Establishment came under national regulatory control which meant that certain facilities and processes at AWE were now subject to external inspection by personnel not normally allowed access to sensitive nuclear warhead facilities and information. In such cases the Ministry of Defence ensures that the inspectors concerned are UK nationals to whom the appropriate security clearance required for the task can be given. However, the same approach could not be given to non-UK nationals who would constitute a multinational inspection team.

Practice Challenge Inspections in relation to the Chemical Weapons Convention (CWC)

30. Since the early 1990s the United Kingdom has conducted a programme of CWC-challenge inspection exercises to develop and test procedures to accommodate international inspectors into sensitive nuclear facilities, such as the Atomic Weapons Establishment and nuclear submarine bases at which nuclear weapons are stored and handled. Arising out of these early inspections, in 1991, it became and is still current UK policy that, in response to a CWC challenge inspection of an AWE site:
 - Access must be given to the inspection team to all buildings on a site;
 - Such access must be managed at all times;
 - The release of classified information can only be considered on a case-by-case basis to demonstrate compliance with the Convention's provisions;
 - There would need to be compliance with Article 1 of the NPT so that no information related to the design of nuclear warheads is to be released.
31. In July 2003, the United Kingdom conducted an exercise to simulate a challenge inspection under the CWC at its nuclear warhead assembly/disassembly facility. Managed access techniques, including negotiation at access points and shrouding, were employed. The exercise was useful in identifying ways to demonstrate compliance under the CWC whilst maintaining National Security. The exercise also demonstrated that the logistics of preparing the site-to-be-inspected for a multinational inspection, whose remit and conduct are outside normal site experience and operation, can be very demanding on both time and personnel resources.
32. It was not too difficult to demonstrate compliance with the CWC but it was clear that demonstrating compliance with any future nuclear warhead reductions treaty would be likely to be considerably more challenging, given that the objectives of inspections under the latter will be very different. The full extent to which this work can be reflected in the nuclear environment has yet to be determined. In relation to the proliferation of sensitive warhead information, the United Kingdom remains fully aware of its obligations under Article 1 of the Nuclear Non-Proliferation Treaty. Further work is required in this area.

Inspection exercises by "international" teams relating to verifying the dismantlement of a nuclear warhead

33. In May 2002 the United Kingdom conducted a "mock inspection" in the assembly/disassembly area of its Atomic Weapons Establishment. This is a highly secure area in which warheads and warhead components are stored, handled and assembled into - or disassembled from - complete nuclear warheads. Visual access to this area would potentially reveal sensitive nuclear warhead design information and access to the area, even for security cleared personnel, is strictly controlled. The purpose of the exercise was to explore the feasibility of carrying out an inspection of security sensitive facilities by non-security cleared foreign inspectors in support of any future treaty verification activities.

34. Managed access techniques, similar to those employed for CWC challenge inspections, were employed and a number of useful lessons relevant to both the inspector and inspected parties were learned. The experience of carrying out this exercise has provided a wealth of information which has helped to clarify the considerable challenges in admitting inspectors into such facilities for verification of nuclear warhead reductions.
35. Although the mock inspection had considerable operational impact and security implications, it is the view of the United Kingdom that, wherever possible, inspections of this type should be accommodated. However, the intrusiveness of this sort of activity presents considerable challenges, many of which we will continue to investigate further.

CONCLUSIONS

36. There are many positive conclusions to be drawn from the studies conducted so far, including:
 - Progress has been made against our objectives set out in the United Kingdom's 2000 paper [1];
 - Managed Access, suitably employed, does permit some form of access for non-security cleared personnel into sensitive nuclear warhead facilities;
 - There is a range of technologies that potentially could aid verification that items in a nuclear warhead dismantlement process are the declared items, but further consideration of many of these is necessary;
 - Some of these techniques do not require direct visual access by personnel not having full security clearances;
 - Experience of visual inspections in sensitive nuclear warhead facilities is available to be drawn upon in any future discussion of the verification of nuclear warhead reductions.
37. However, it would be wrong to conclude that any of this would be straightforward. Areas requiring further consideration include:
 - Determining and managing the degree of access that can be given to multilateral inspectors without compromising sensitive information;
 - Determining the extent of confidence that can be obtained from techniques that do not require direct visual access to a nuclear weapon or its components; and
 - Establishing an adequate chain of custody process without compromising sensitive information.
38. The United Kingdom is continuing this work through its Ministry of Defence. The aim continues to be to obtain information and knowledge on technologies and methodologies that address security and proliferation concerns and which could be applied in the verification regime of any international arrangement for the decommissioning and dismantling of nuclear warheads and the disposition of any resulting surplus material. The United Kingdom will

present a consolidated report of the work at the 2005 NPT Review Conference that will summarise the various technologies and approaches investigated in the five-year study.

References

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Table 1: Techniques that could have some utility in inspections

Technique	Comment
Tags and seals	Requires access by inspector to containers but not necessarily to the component
Remote monitoring	No direct access required but need to ensure that sensitive information is not transmitted
Item tracking	Could require direct access by inspector
Portal monitoring	No direct access required by inspector
Sampling and analysis of materials	Some form of access required but sampling could be done by host site 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
Environmental monitoring	No direct access required if limited to the building environs
Paper and computer records	No direct access required but information contained could be classified

FIGURE 1
VERIFYING NUCLEAR WARHEAD
DISMANTLEMENT

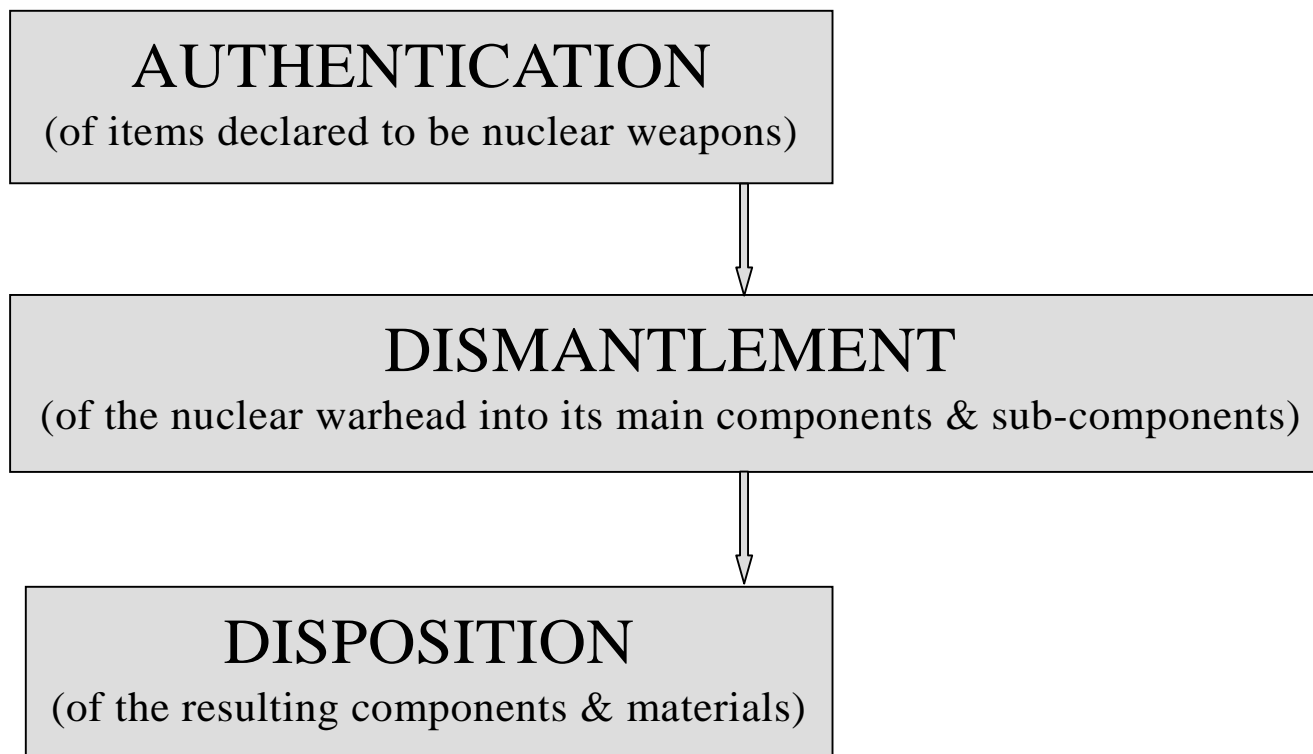


FIGURE 2

GENERIC DISMANTLEMENT PROCESS

