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Review of the U.S.-U.K. Warhead Monitored Dismantlement Exercise

Danielle K. Hauck and Iain Russell

Abstract

In 2010 and 2011, the U.S. and U.K. undertook a warhead monitored dismantlement (WMD) exercise to investigate methods for how two nuclear countries could verify each other's compliance in an arms reduction treaty. Back stories were created for Tachonia (played by the U.S.) and Avalonia (played by the U.K.). The two fictional countries negotiated the use of both non-destructive analysis (NDA) measurement equipment and chain-of-custody (CoC) equipment for use during the monitoring regime. Avalonia and Tachonia then negotiated a monitoring protocol including procedural details for the use of the monitoring equipment. The exercise culminated with a monitoring visit to verify the dismantlement of an Avalonian warhead. The exercise monitoring protocol is described and lessons learned for the joint design process, managed access to sensitive host facilities, monitoring procedures and equipment design are discussed. Ongoing work that is implementing the lessons learned from the exercise is also briefly described.

1. INTRODUCTION

A mock historical background was developed for Tachonia and Avalonia- two fictional regional powers that had engaged in a nuclear arms buildup but were now interested in stockpile reductions. The mock agreement required both sides to reduce deployed stockpiles by 20 warheads each and included provisions for reciprocal monitoring of dismantlement, followed by monitored storage of fissile material. Avalonia had agreed to dismantle 20 of its 'Dwrch Daear' (DD) nuclear landmines. The exercise participants were given a mock Verification Protocol which outlined provisions for a familiarization visit and a monitoring visit to Avalonia.

Avalonia issued a declaration stating that the DD was a single-stage plutonium-based warhead with no uranium. The declaration also provided for the direct measurement confirmation of the following DD attributes: 1) the presence of plutonium, 2) the plutonium-240 to plutonium-239 ratio is less than 0.1, and 3) the plutonium has a mass of at least 500 grams. An additional provision for confirming the presence of high explosive (HE) in the DD (thus effectively representing a fourth DD attribute) was agreed during the protocol negotiations.

The exercise covered development and deployment of the monitoring regime, from the signing of the treaty to dismantlement of the first warhead, and included many aspects of a real monitoring regime, including negotiating the monitoring protocol, working in an operational nuclear facility, and performing measurements on a realistic item containing weapons grade plutonium [1,2].

Monitoring Teams

For the purpose of the exercise, the Tachonian Team was played by scientists from U.S. national laboratories and government departments. The Avalonian team was played by staff from the U.K. Atomic Weapons Establishment (AWE). The Burghfield site at AWE represented the Avalonian dismantlement facility. The Avalonian and Tachonian parties adopted parallel organizations shown in Figure 1. As host party to the first monitored dismantlement, Avalonia required additional facility and security representatives.

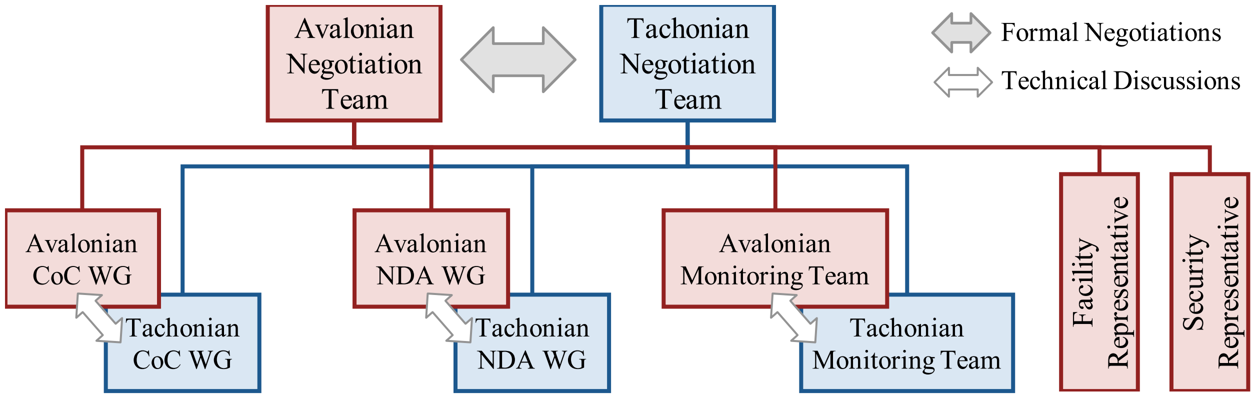

Figure 1. Parallel Team Structure in Avalonia and Tachonia leading up to the monitoring visit

The Chain-of-Custody (CoC) and Non-destructive Assay (NDA) Working Groups (WGs) were responsible for developing a technically feasible monitoring approach, selecting monitoring equipment, and drafting technical procedures. The Negotiation Teams addressed unresolved technical issues and negotiated the final monitoring protocol, procedures and selection of monitoring equipment. Each party identified a monitoring team made up of members of the NDA and CoC WGs for carrying out the monitored dismantlement. During the monitoring visit the Monitoring Team Leaders were responsible for negotiating the response to unforeseen monitoring difficulties. However, any unresolved difficulties were escalated to the negotiation teams.

Familiarization Visit; Avalonia (AWE, Burghfield), Mar 21-24, 2011

Tachonian representatives travelled to Avalonia to become familiar with the Avalonian dismantlement process that would be monitored. The Tachonian representatives were given an overview of the Avalonian dismantlement process that would be monitored, and were allowed to tour and document information about the dismantlement facility, the containers that would be used during dismantlement, and the loading bay where the DD would be received at the dismantlement facility. Initial meetings of the Negotiation Team, CoC WG and NDA WG took place to begin discussing monitoring equipment and approaches.

The Avalonian team gave scripted tours, and collected questions so that responses could be reviewed and approved before responding to the Tachonian team. Sensitive facility features were shrouded for security reasons. Avalonia imposed realistic restraints on the visitors, including full protective clothing, and disallowing pens, notebooks or other items that had not been provided by Avalonia. Photographs were taken by Avalonian team members upon request and released to Tachonia after conclusion of the familiarization visit and a security review.

NDA WG Meeting and Technical Demonstration; Tachonia (SNL), May 16-19, 2011

During the NDA WG Meeting, Tachonia presented and demonstrated potential radiation measurement equipment for monitoring. The meeting included demonstrations of the proposed equipment and technical discussions regarding the equipment, types of measurements and measurement procedures. The technologies demonstrated at the meeting formed the basis of the monitoring equipment that would be used. Since equipment development was not one of the primary project goals, emphasis was placed on equipment that could be used as is – even if they were not optimal solutions, or with minor modifications. In many cases modifications (such as the addition of an information barrier) would be required. However, due to time constraints only selected equipment could be developed or modified within scope of the exercise.

CoC WG Meeting and Procedural Walk-through; Tachonia (PNNL), July 25-29, 2011

The participants reviewed the list of proposed measurement systems and monitoring equipment for use during the monitoring visit, and chronologically stepped through the events of the monitoring visit. The participants also discussed several specific CoC issues including data management, radiation surveys, door and container seals, and video surveillance. A room-within-a-room concept [3] was developed because Avalonia had concerns regarding Tachonian inspection of facility walls and a viable technology for inspecting walls for hidden penetrations was not available. The room-within-a-room consisted of a temporary wall within the facility that could be inspected by the monitoring party and which permitted video surveillance of the area between the facility and temporary wall. Finally, the participants performed a full walkthrough of the notional monitoring visit. The draft monitoring procedures were updated based on the results of this meeting.

Negotiation Visit; Avalonia (AWE), Oct 3-6, 2011

The Tachonian and Avalonian Negotiation teams met to negotiate the agreed protocol and technical procedures, with experienced negotiators leading both parties. The informal technical agreements that had been reached by the WGs, regarding selection of monitoring equipment and high level procedures, formed a basis of understanding between the parties. However, several key aspects required substantial negotiation, and the atmosphere became tense during the discussion of contentious issues.

Authentication Visit; Avalonia (AWE), Oct 31-Nov 4, 2011

A Tachonian team travelled to Avalonia to prepare and authenticate the agreed monitoring equipment, and to provide recommendations regarding which pieces of equipment should be trusted for monitoring use. Activities included conducting an inventory of and inspecting CoC equipment, functionally testing and performing other authentication checks on measurement equipment, setting up the video surveillance computer network, and taking initial photographs of tamper-indicating enclosure welds, adhesive seals and other unique identifiers.

Monitoring Visit; Avalonia (AWE, Burghfield), Nov 7-18, 2011

The Tachonian monitoring team traveled to Avalonia to monitor the dismantlement of the first DD. The item used to represent the DD was a nuclear explosive-like assembly containing kilograms of plutonium and an inert HE simulant, although this was unknown to the monitoring team at the time. The Tachonian monitoring team was made up of ten individuals, five of which were permitted in the facility at a given time. The Avalonian monitoring team typically included 13 – 20 personnel in the monitored area at a given time and was made up of workers to perform the dismantlement, workers to perform the monitoring activities, facility escorts, and health physics support.

Pre-dismantlement operations included setting up the monitoring equipment and performing attribute measurements on the DD. The Tachonian team temporarily left the facility for the duration of the dismantlement operations. Post-dismantlement operations included attribute measurements on the dismantlement components, and sealing equipment for the next monitoring visit. The monitoring protocol is described in Section 2.

Exercise Wash-up Meeting; Tachonian (NNSA HQ), Dec 13, 2011

The participants reviewed the Tachonian monitoring visit report and the Avalonian host responses to the visit report, and discussed items that needed to be covered at the next meeting of the Monitoring Review Committee. This concluded the “in role” activities as part of the project.

2. SUMMARY OF THE AGREED MONITORING PROTOCOL

A layout of the monitored area is shown in Figure 2 and a summary of the agreed monitoring protocol is shown in Figure 3. For brevity, individual technologies are not discussed in this paper, but references are provided wherever available.

The first primary task during the monitoring visit was to setup the monitoring system, including; inventory and setup of monitoring equipment, reference photography of the temporary walls, seals, floor and other unique identifiers, and set up the fiber optic tamper indicating enclosure (FOTIE) [4] for storage of small monitoring tools.

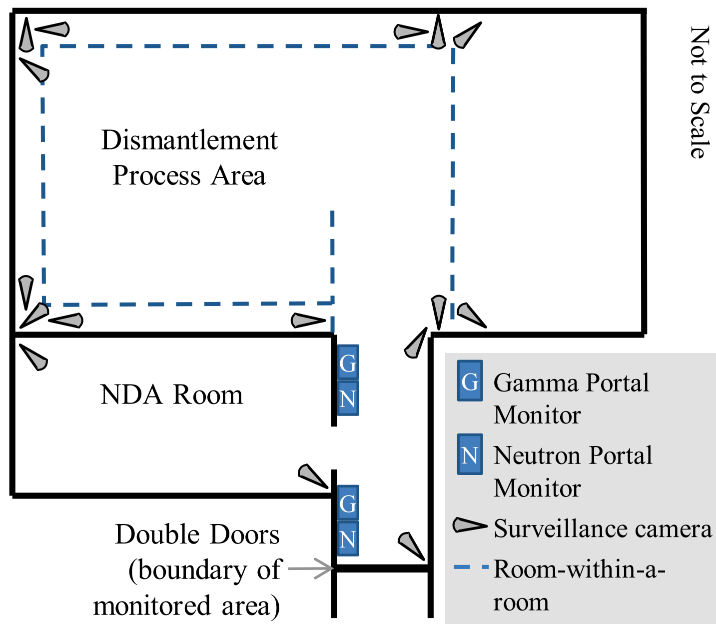

Figure 2. Layout of the monitored area.

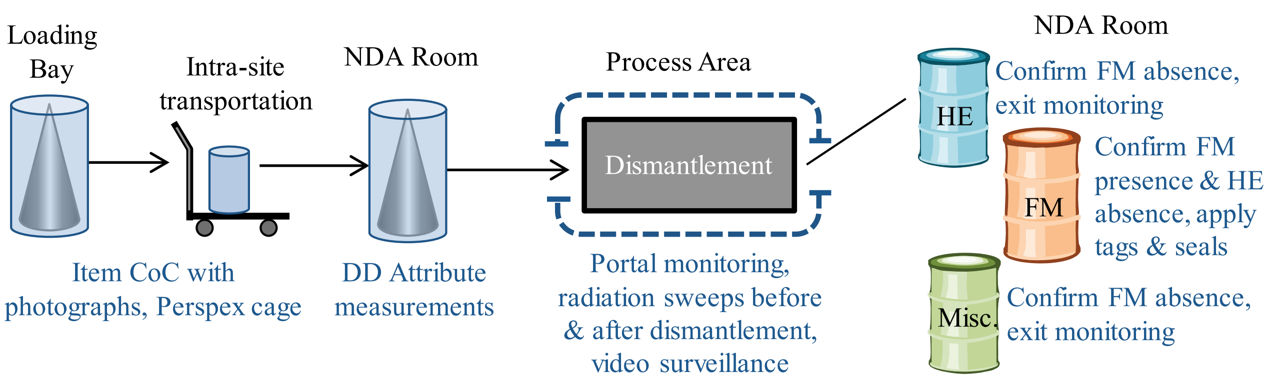

Figure 3. Overview of the monitoring regime and confirmation measurements

Monitoring began when the DD reached the loading bay. The monitoring team was not permitted to observe movement of the DD from the loading bay to the NDA room. Instead, agreed CoC of the DD during transport included change detection photography of the welds on the DD container and application of a Perspex cage. When the DD arrived at the NDA room, the monitoring team inspected the Perspex cage and seals, and took reference photographs of the container welds.

Measurements on the DD and empty component containers were performed in the NDA room. Attribute measurements were performed on the DD to confirm: 1) the presence of Pu with the Trusted Radiation Attribute Demonstration System (TRADS) [5] and the Ortec Fission Meter, 2) at least 500g of Pu with TRADS and the Fission Meter, 3) a 240Pu to 239Pu ratio less than 0.1 with TRADS or the Ortec Detective as back-up, and 4) the presence of HE in the DD with Portable Isotopic Neutron Spectroscopy (PINS) [6]. In addition, a Trusted Radiation Identification System

(TRIS) [7] template measurement of the DD was taken to confirm consistency of each dismantled item for future reference.

Empty containers for receiving the dismantled components included two X1 containers and one X2 container designated for HE components, three F1 containers for fissile material components, and two N1 containers for all other components. All empty containers were monitored with the Fission Meter to confirm absence of Pu.

The DD was moved from the NDA room to the process area for dismantlement. The Tachonian monitors then exited the dismantlement facility for the duration of dismantlement operations. Several monitoring tools and approaches were used to prevent diversion of fissile material during the dismantlement, including seals on doors, video surveillance, room-within-a-room, photographic change detection of the floor, radiation sweeps of the monitoring area before and after dismantlement using the GMS295 survey meter, and portal monitors [8].

Following dismantlement the F1 containers were moved to the NDA room. The full X1, X2 and N1 containers, as well as the empty DD container, were measured with the fission meter and swept with the survey meter to confirm absence of fissile material. Measurements were then performed on the F1 containers to confirm absence of HE and to reconfirm plutonium attributes. The absence of HE was confirmed using PINS. Measurements were then performed on the aggregate of the F1 containers to confirm Pu presence (TRADS and Fission Meter), Pu mass of at least 500g (TRADS and Fission Meter), and plutonium-isotopic ratio less than 0.1 (TRADS). The F1 containers were tagged and sealed for future monitoring.

At the end of the monitoring visit, final sweeps were performed of each room in the monitored area. All monitoring equipment was sealed and moved into storage where they would remain until the next monitoring visit.

3. LESSONS LEARNED

Several detailed lessons learned were identified regarding measurement equipment for arms control scenarios, including designing equipment for deployment in a realistic nuclear facility, and certain limitations of existing attribute measurement systems. However, the purpose of this paper is to provide an overview of the exercise and high-level lessons learned. This section summarizes high level observations that were identified and discussed during the exercise wash-up meeting.

Conflict Despite Best Intentions

Some points of the monitoring visit exemplified a cooperative atmosphere and a general willingness, for example, to discuss work-arounds or procedural modifications when unanticipated problems arose. At other times the interactions were conflict-driven. Conflict arose from disagreement over the authentication process during the Authentication and Monitoring visits; the high demand on the host to provide resources including radioactive sources, laboratories, equipment and support personnel, all during active engagement of foreign nationals, the demand on the host to review large amounts of data within the agreed 24 hour timeframe and the monitoring ramifications when the reviews could not be completed; and portions of the procedures that were written vaguely or ambiguously and that were interpreted differently by the two parties. Many of the issues discussed below contributed to conflict.

The Nature of Host Confidence

The host and monitoring parties had different expectations regarding which party had a stake in the monitoring equipment authentication activities. The monitoring party expected to be the sole stakeholder in authentication activities for the purpose of confirming the treaty declarations. The monitoring party did not expect to justify its reasons for performing certain authentication tasks or to justify its rationale for recommending whether a piece of equipment should or should not be used in the monitoring regime. However, the host party expected to have an equal stake in authentication activities, in part because improperly handled authentication activities could result in wrongful non-verification of the treaty.

Attempts by the host team to be involved in the authentication activities, and requests for justifications of monitoring party decisions felt intrusive and controlling. Monitoring party rebuffs to the host team reduced the host's confidence in the sincerity of the monitoring party for cooperative monitoring. It may be necessary to implement host-only or joint solutions to provide the host country with confidence that they will not be falsely accused of breaking treaty obligations.

Complexity of the Monitoring Regime

The procedures for the monitoring regime became more complex than originally anticipated. The complexity of the procedures and the time constraints contributed to a perception of chaos which impacted monitor confidence in the legitimacy of the activities, host confidence in the safety and security of the regime, and was a breeding ground for conflict. For example, both sides were constantly under time pressure and individuals on both sides inadvertently diverted from agreed procedures. Some of the challenging aspects of the monitoring regime were the large number of activities required to setup and maintain the monitoring regime, the large numbers of personnel present, underestimation of time required to perform activities, and the need to work around facility constraints. In general, procedures require substantial thought, walk throughs and development iterations.

Authentication and Certification of Equipment

Within the exercise, mutual trust of small inexpensive equipment such as SD cards was established through host certification of a large number of copies, followed by random selection for private inspection by the monitoring party. The approach for large monitoring equipment was private host certification of the equipment, followed by monitor inspection (e.g. visual inspection, X-rays, etc.) in the presence of the host party. Due to deliberate project decisions, the exercise did not fully explore methods for authenticating the measurement equipment. Nonetheless, the project highlighted the need for further investigation into inspection tools and procedural approaches for simultaneous host and monitor confidence.

To facilitate confidence it may be necessary to share detailed information about the measurement equipment. It may be necessary to share underlying scientific theory, implementation methods source codes, and detailed design documentation. This may be difficult for complicated equipment, and difficult or impossible for equipment with proprietary, sensitive or export controlled features.

It may be difficult to identify appropriate locations in or near the host facility for monitor authentication activities. Within project scope it was not possible to identify a host facility which allowed the monitoring team (foreign nationals) to use their own tools for authenticating the monitoring equipment, and which allowed access to resources for testing the radiation measurement equipment such as test sources and liquid nitrogen. It was necessary to divide the monitoring team between separate locations to accomplish the authentication tasks and this resulted in loss of productivity, lack of communication and loss of monitor confidence.

Equipment would need to be designed to facilitate authentication inspections without impacting host confidence in the safety or security of the equipment. The participants attempted to develop an authentication approach within the constraints of the project scope. However, the technical and procedural difficulties associated with authentication of host-certified equipment were complex enough that this could not be satisfactorily accomplished within the project. Notional joint design was adopted to allow the project to progress.

There are several issues associated with functional testing of equipment. Lack of inspector autonomy in the facility, and logistical challenges associated with authenticating the radiation test sources were among the major issues; these were not fully resolved within the scope of the project.

It may be difficult to write mutually agreed procedures for the authentication process. The host party wanted the procedures to be as constrained as possible to facilitate continuity of knowledge over the equipment during the monitor inspection, and enforced the procedures exactly as they were written. The monitoring team did not wish to divulge the exact nature of the authentication activities such that the host could learn how to modify equipment to avoid detection. The monitoring party felt that the procedures should describe the types of activities permitted, such as taking photographs of equipment and applying agreed tamper-indicating devices, and that the exact implementation of these activities should be up to the monitoring party, as long as the tasks did not violate safety regulations, or equipment certification.

Managed Access

It was necessary to develop a managed access strategy that allowed the monitoring party to monitor the dismantlement while protecting sensitive host information. Host concerns included protecting information regarding the DD, as well as protecting sensitive information about the facility. The host party is also responsible for ensuring that onerous safety conditions required for the processing of nuclear explosives are not compromised by the monitoring regime. Some specific considerations are described here.

Additional host personnel may be needed. In addition to the facility personnel that perform the dismantlement, additional host personnel were identified to perform work at the request of the monitoring party (according to the procedures), and to supervise and escort the monitoring personnel. Both sets of additional host personnel serve to limit monitoring party access to the facility and the potential loss of sensitive information. The large number of people present (five monitors plus five host workers plus seven to eight host escorts) had ramifications on room safety limits, procedures, and host and monitor confidence.

It is challenging to identify the required facility resources, and to perform the associated safety and security reviews to meet all of the monitoring needs. In itself the presence of foreign nationals poses safety and security challenges. To support the monitoring regime it is necessary to simultaneously coordinate the warhead disassembly operations, the use of radioactive test sources, the use of large monitoring equipment, and the use of chemicals such as liquid nitrogen. During the authentication week in particular, the monitoring party required the ability to supply and operate their own authentication equipment. These needs place challenges on the facility with regard to identifying appropriate facility locations, and potentially developing new safety and security plans.

Shrouding is one approach to protecting sensitive features, but may also pose challenges for the monitoring regime. The monitoring party was escorted through the host facility on a shrouded bus. The personnel were then escorted down a specially designated, fully shrouded path through the dismantlement facility to reach the monitored area. Additional shrouding was used to protect sensitive facility features in the monitored area. In some cases, shrouding resulted in the need for the monitoring party to perform additional radiation sweeps. In addition, accidental loss of shrouding resulted in host redaction of portions of video surveillance data.

Effective Monitoring through Redundancy

The monitoring system was able to identify errors and deviations from procedures and this increased confidence in the monitoring system capability. For example, the breakbeam identified an unauthorized entry into the NDA room and the surveillance cameras captured an unexpected entry into the room-within-a-room, as well as an unauthorized movement of a table into the process area.

The monitoring system also had sufficient redundancy to address temporary loss of data from some monitoring equipment. For example, the breakbeam provided confidence that the NDA room had not been entered despite the fact that surveillance video had been redacted due to the presence of unshrouded F1 containers, the PM neutron data provided confidence that there was no movement within the monitored facility when the surveillance camera view was blocked by shrouding, and the portal monitors provided confidence that radioactive material had not been diverted when the Tachonian monitors were unexpectedly forced to leave the dismantlement facility.

While redundancy improves monitoring confidence, it also increases the complexity of the monitoring regime and procedures, and may introduce host information protection concerns.

Data Management

Both parties were heavily burdened by the large amount of data that was created. In total, about a terabyte of data was collected, consisting mostly of video data from the surveillance system, change detection photographs and portal monitor data. The host team reviewed all data for security purposes before it was released to the monitors. Neither team was able to keep up with the pace of data reviews.

Photography was a convenient in-field approach to maintaining CoC on many items (the floor, walls, seals, container welds, etc.) but reviewing hundreds of pictures was extremely burdensome on both teams, even with the use of change detection software [9]. It was necessary to track hundreds of secure vials containing duplicate SD cards with host and monitor copies of monitoring data. Data were temporarily lost at least once due to the complexity of the SD card management procedures. All 17 video surveillance cameras and all four portal monitor modules were operational 24 hours a day, resulting in a large amount of data to review. In addition, it was often difficult to correlate the corresponding video and portal monitor data. Monitor review of data continued for several months following the monitoring visit.

As discussed above, redundancy in the regime reduced the possibility of a loss of monitoring coverage due to unexpected events. A reduction in the monitoring redundancy would reduce the procedural complexity and the burden associated with data management. However, reducing monitoring may also result in a decrease in monitor confidence. Key trade-offs between procedural complexity, monitoring effectiveness and data management need to be considered.

Warhead Confirmation Attributes

The exercise highlighted the limitations of using simple warhead confirmation attributes and the challenges of measuring those attributes. The neutron-based method for measuring the plutonium mass attribute is limited by the measurement time, the number of multiplicities used in the analysis, and assumptions regarding detector efficiency. The gamma-based method for measuring the mass attribute is limited by the self-attenuation of gamma-rays by the item itself and the isotopic analysis is complicated by large amounts of HE. Confirmation of HE presence required active interrogation with a neutron source and relied on the detection of nitrogen due to the challenges of defining additional characteristics that are useful, negotiable and measurable. Finally, although measurement confirmation of the absence of HEU was considered, it was not implemented due to the lack of availability of existing appropriate measurement systems.

4. FOLLOW-ON WORK

Several areas of potential follow-on work were identified by the exercise participants. This section discusses threes areas of follow-on work that are currently being pursued.

Next Generation Adhesive Seal

The adhesive seals used in the exercise were not sufficiently unique for arms control purposes and it was necessary to apply additional unique identifiers, usually in the form of signatures, on each seal. Work is ongoing for the development of a Next Generation Adhesive Seal which is being developed specifically for arms control scenarios with multiple layers of unique identification.

Change Detection Software

Change detection software was used within the exercise to facilitate comparisons of before and after photographs of many seals, unique identifiers, and tamper-indicating enclosures. The change detection software was very helpful for effectively identifying changes in the photographs. However, several deployment considerations were highlighted regarding the use of change detection software including the amount of time required to organize the photographs, the challenges associated with aligning photographs, and the need to run the software on a PC. Since the exercise, the change detection software has been updated to include batch processing with automatic categorization and alignment of photos, additional in-field and software tools for aligning photographs, and a mobile version that can be deployed on any android-based device.

Portal Monitor for Authentication and Certification

Portal monitors improved monitor confidence in the dismantlement activities by preventing diversion of plutonium into or out of the dismantlement process. However, the exercise highlighted that portal monitors for arms control deployment have potential design requirements that are not met in existing systems, such as specialized data output, tamper-indicating features and limits on extraneous functionality. In addition, working with a treaty partner to design and select monitoring equipment presented more challenges than anticipated and further work was needed to identify reliable options for simultaneously providing host and monitor confidence in the equipment. Following the exercise, the U.S. and U.K. agreed to undertake the Portal Monitor for Authentication and Certification project to understand how treaty partners might work together to develop and deploy a specific piece of monitoring equipment to jointly address these host and monitor concerns.

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