Examining the utility and readiness of mobile and field transportable laboratories for biodefence and global health security-related purposes

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ABSTRACT
Mobile and field transportable laboratories have long been used by military and defence, intergovernmental inspections, health, and environmental monitoring agencies. Among the purposes of deploying such laboratories are early warning, forward reconnaissance, on-site investigation, verification, and response. With the advent of technology that has enabled the use of diagnostic equipment in the field and extended transportation capabilities to rapidly deliver these assets and services, mobile and field units have served to further extend networks of existing, fixed laboratories. Case histories of example mobile and field transportable laboratories are compared and discussed including those used by the United States military, Finnish Defence Forces, United Nations, and several mobile and transportable diagnostics laboratories used in response to the 2014 outbreak of Ebola virus in West Africa. Given the often-remote locations to which these laboratories are deployed, they must incorporate a high degree of self-sufficiency, particularly with regard to utilities, and integral biosafety and biosecurity measures. Experienced scientists performing similar technical tasks in fixed laboratories can be employed to support and refine the mobile and field laboratory operations. Mobile and field transportable laboratories are usually national-level assets that require ongoing funding for maintenance, equipping, resupply, and training of personnel in order to maintain a readiness posture for their intended missions. We also examine the cost estimates and sustainment challenges of operating and maintaining these laboratories to provide recommendations and lessons learnt for their practical use and deployment.

Science knows no country, because knowledge belongs to humanity, and is the torch which illuminates the world.

– Louis Pasteur

1. Introduction
Extending surveillance capabilities beyond the foci of a fixed laboratory has been practised through a tiered laboratory system that typically includes a central laboratory supported by a network of regional and local laboratories. Portable field, fixed (e.g. trailer) transportable, and mobile laboratories can further extend expeditionary capabilities to austere and resource-limited areas. With the advent of motorised vehicles, either wheeled or treaded, the scale of laboratory deployments has increased in similar magnitude to the use of mobile vehicles for educational, health care, and other utilitarian applications.

The Russian Anti-Plague (AP) system, which Czar Nicolas II created in the 1890s, is perhaps the best example of an integrated, tiered epidemiological surveillance system. The AP system, which focused on natural outbreaks such as cholera and zoonotic disease (brucellosis, plague, and tularemia), required close coordination among veterinary and public health agencies and focused upon the environment where a disease outbreak occurred (McNamara, Platonov, Elleman, & Gresham, 2013). Field laboratories were established to respond and mitigate outbreaks in endemic areas while medical observation posts at border stations and maritime ports monitored for the importation of transboundary disease (Melikishvili, 2006). Before motorised vehicles, AP teams deployed to the field by horse and covered wagon to treat patients and investigate outbreaks. As suggested by Dr Gradzhanov, these deployments that occurred through Russia and former republics in central Asia may be considered as examples of the first mobile laboratories (Yeh, 2010). The AP system also deployed a train laboratory with several specialised cars staffed by professionals that travelled by rail in response to the 1921 plague outbreak in the Russian Far East (McNamara et al., 2013).
Currently mobile and field transportable laboratories can be deployed by air, land, rail, and sea. These include platforms such as trailers or containers which require additional truck transport and those which are drivable. US government agencies in military and defence, law enforcement, regulatory, and environmental protection have deployed mobile and field transportable laboratories to support missions for Countering Weapons of Mass Destruction (CWMD) or chemical, biological, radiological, nuclear (CBRN), and explosives detection, mitigation; forensics, and environmental analysis (Edgewood Chemical and Biological Center, 2008). In 2002, the United Nations Monitoring, Verification, and Inspection Commission (UNMOVIC) also deployed one of the first CWMD analysis laboratories in Iraq prior to the Second Gulf War to support their on-site inspections and disarmament mandate (United Nations Security Council, 2003).

In this article, we present case histories involving the use of mobile or field transportable laboratories to compare and contrast their capabilities and operations. The discussion will focus on biodefence applications such as detection of biothreat agents related to CWMD and infectious disease outbreak response missions. While these missions are distinct, the establishment, recruitment, asset development and maintenance, readiness, and sustainment requirements are similar. Establishment of the CWMD mission in the US and the European Union (EU) since the 1990s including international conventions and norms, programmatic doctrine, operational perspectives, and other requirements is referenced. The authors pose that a CWMD mobile and transportable laboratory model will apply to an infectious disease outbreak and public health preparedness response as related to continuity of operations and transition of duties to partner countries (Tables 1–4).

## 2. Case histories

Since the 2000s, the US National Guard Civil Support Teams (CSTs) have deployed domestically on dozens of missions, several international agencies have deployed globally, and others such as the Finnish Defence Forces (FDF) maintain a state of readiness. The UNMOVIC chemical and biological analytical mobile laboratory deployed to Baghdad, Iraq, was their on-site sample processing and screening (United Nations Security Council, 2003). This laboratory was constructed of a shipping container that was air transportable and powered by a large diesel generator. Prior to the 2014–2015 Ebola virus (EBOV) outbreak, a transportable biosafety level 1 laboratory was constructed from a 40 ft. (12.2 m) shipping container that contained equipment to test cerebrospinal fluid for meningitis (Nepomnyashcha, 2017) and samples during a 2005 Marburg outbreak in Angola (Grolla et al., 2011). To examine the technical and operational challenges for standing up and sustaining mobile laboratories, we describe four actual case histories for three CWMD mobile laboratories in operation since 2004 and for select mobile laboratories deployed in response to the 2014–2015 EBOV outbreak, the largest in history that resulted in over 11,000 deaths (Flint et al., 2015). Our analysis presents information from open-source internet searches that includes literature searches of cited references for some of the mobile laboratories represented here. Mobile laboratories deployed for military operations are often a smaller component of a larger unit with greater human resources, equipment, and logistics tail (Figure 1).

Designing and deploying a field transportable laboratory in an austere field environment presents several challenges for civilian and military operations. This was especially evident during the EBOV outbreak because affected locations lacked strong public health infrastructure. The mobile laboratories deployed played...
Table 2. Common applications of mobile and field transportable laboratories.

| Agency or organisation type                                      | Mission, capability                                |
|----------------------------------------------------------------|---------------------------------------------------|
| Military, defence                                               | CWMD, CBRNE, treaty verification                   |
| Intergovernmental, international inspections                    | Verification of chemical, biological WMD disarmament |
| Public health                                                   | Infectious disease surveillance, outbreak response |
| Law enforcement                                                 | On scene and forensic investigation (e.g. evidence collection, processing) |
| Regulatory                                                     | Environment (soil, water)                          |
| Agricultural, veterinary health                                 | Transboundary animal disease                       |

Table 3. Comparison of biological detection capabilities of mobile and field transportable laboratories that have been deployed.

| Mission                      | CWMD                     | EBOV response (2014–2015 outbreak) |
|------------------------------|--------------------------|-----------------------------------|
|                              | Platform                 | Specs                             | |
|                              | BIOSafety equipment      | CST                               | FDF    |
|                              |                         | Truck, Class III, II BSCs         | Trailer, Class III, II BSCs |
| Immunoassay                  | +                        | +                                 | +      |
| qPCR                         | +                        | +                                 | +      |
| Microscope                   | +                        | +                                 | +      |
| Automated sample preparation | +                        | +                                 | +      |
| Freezers                     | +                        | +                                 | +      |
| Power                        | 2+                       | 7+                                | 4      |
| Number of personnel          | 2+                       | 7+                                | 4–5    |

Notes: Examples are used by military, defence agencies in CWMD missions and infectious disease outbreak response. The + or - sign denotes whether that laboratory has known capability for that spec or not (i.e. yes or no). UNMOVIC, which performed non-proliferation inspection activities, deployed a biological analytical laboratory that was equipped with qPCR, immunoassays, and power.

Table 4. CST ALS start-up and annual operational and sustainment costs.

| Start-up item                                      | Cost (US$) |
|----------------------------------------------------|------------|
| ALS vehicle with instrumentation                   | 232,000    |
| Operator initiation (travel costs for two staff*)  | 45,000     |
| Operator salaries (two staff*)                     | 118,308    |
| Operator housing and subsistence allowances (two staff*) | 30,408   |
| ALS reagents (immunoassays and PCR assay kits)**   | 10,000     |
| ALS consumables (chemicals, labware, and PPE)      | 10,000     |
| Total                                              | 445,356    |

| Annual operational and sustainment item             |            |
|----------------------------------------------------|------------|
| Operator sustainment training (travel costs for two staff*) | 20,000    |
| Operator salaries (two staff*)                      | 118,308    |
| Operator housing and subsistence allowances (two staff*) | 30,408   |
| ALS reagents (immunoassays and PCR assay kits)**   | 10,000     |
| ALS consumables (chemicals, labware, and PPE)      | 10,000     |
| Warranties and equipment replacement                | 50,000     |
| Total                                              | 238,356    |

Notes: Given are estimated costs commensurate with a domestic US National Guard CST mission (Interagency Board, 2017) without additional costs that an international mission would require (Rosenberg, 2007).
*Staff are one E-6 soldier and one O-3 officer.
**Test kits and reagents provided by the DBPAO (DOD, 2017).

During the 1990s the US began to develop a strategy to enhance domestic preparedness to respond to WMD attacks by assigning resources and responsibilities through funding and legislation. The Defence Against Weapons of Mass Destruction Act mandated enhancements of preparedness and response activities in the US (United States Code, 1996). General Stephen Blum, who was the chief of the National Guard Bureau, advocated that the National Guard play a leading role in domestic preparedness because of existing community links, familiarity with local geography, and the existence of facilities and troops in local communities (Buchalter, 2007). The US Department of Defense (DOD) commissioned a 'Tiger Team' to develop a strategic plan for response to attacks using WMDs, gaps identified in the study led the team to propose Rapid Assessment and Initial Destruction (RAID).
National Guard teams as a potential solution (DoDTiger Team, 1998). Congress then authorised funding to establish RAID teams, one in each Federal Emergency Management Agency region. As with other ‘part-time’ units in the National Guard, the ‘full-time’ RAID teams were manned and trained with federal funding and commanded by officers under the authority of elected governors of their respective states. Shortly thereafter the units were renamed as Civil Support Teams and the National Defense Authorization Act authorised funding for the establishment of 55 teams, one in each US state and territory (NDAA, 2003).

Each National Guard CST is an asset of that state under their governor’s direction and comprised 22 full-time Army and Air Guard personnel. Their mission is supporting civil authorities at domestic chemical, biological, radiological, and nuclear incident sites by identifying suspect agents, assessing current and projected consequences, advising on response measures, and assisting with requests for additional support. (NGR500-3, 2011) In practice, CSTs provide assistance to civilian first responder colleagues such as hazardous materials teams, police, and fire personnel. CSTs require approximately 18 months to become certified for ‘live’ missions through extensive individual and team training coursework, culminating with an external evaluation. With the additional second teams in the states of California and Texas, a total of 57 teams achieved this status by 2009 and have remained in continuous operational status with external evaluations occurring every 18 months to ensure readiness maintenance of personnel, equipment, and procedures (USDOD, 2009). CSTs are organised into six sections: Command, Operations, Administrative and Logistics, Communications, Medical, and Survey each team fields an Analytical Laboratory System (ALS) in its Medical section while the Survey section serves as the organic response team to monitor chemical and radiological emissions and collect samples for chemical and biological analyses in the ALS.

The ALS working area features a Class III glovebox with integrated butyl rubber gloves and a Class II biosafety cabinet (BSC) with sliding sash that is connected to an exterior sample pass-through box. The ALS includes an on-board diesel-powered generator and a mini refrigerator and freezer for storage of equipment standards, reagents, and handheld immunoassay test kits. The ALS equipment suite features a gas chromatograph-mass spectrometer (GC-MS) for use in identification of volatile chemical samples; a microscope with lenses and accessories suitable for the performance of visible light, polarised and Fourier transform infrared spectrometry microscopy, for use in identification of liquid and solid chemicals and cultured biological agents; and a real-time, quantitative polymerase chain reaction (qPCR) thermocycler for use in identification of nucleic acid signatures of biological agents such as anthrax. Refrigeration and power to support equipment is provided by on-board generation or shoreline power and the vehicle is air transportable by C-130 aircraft.

The working area is designed for two people, a lead laboratorian entitled as a Nuclear Medical Science Officer and an assistant laboratorian who carries an additional role of monitoring health and readiness of team personnel, entitled as a Medical Non-Commissioned Officer. The ALS carries various reagent sets and standards and one handheld immunoassay test kit for identification of CDC category A, B, and C biological agents. The ALS team, which works in closely with local public health partners, can share equipment data and results including sample photos from a ‘hot’ site via hardware and connectivity resources provided by the CST Communications team. Following sample preparation and a standard sequence of analyses, any samples merit further analysis (as deemed in coordinated, real-time...
communication between the ALS team and their public health partners) are packaged in the ALS and delivered to receiving local public health laboratories in an expeditious manner. The ALS is scheduled for upgrade and rebrand as the Common Analytical Laboratory System in 2018, which will become the CST platform as well as select US Navy, Marine Corps, Army, and Air Force units (Joint Program Executive Office Chemical Biological Defense, 2014).

2.2. Finnish mobile diagnostic CBRN field laboratory

The Finnish mobile diagnostic CBRN field laboratory (CBRN Field Lab) presently in use is an asset of the FDF and was developed during the early 2000s by a joint effort of military and civilian participants. The CBRN field lab can be used for domestic and international missions, and for all three major tasks of the CBRN as defined in the Finnish Act on the Defence Forces (Ministry of Defence of Finland, 2008); to the national defence of Finland, to support other Finnish authorities in national security, and to aid international crisis management operations. The FDF deployed their CBRN field laboratory as part of their participation in the 2007–2008 EU Battlegroup and operate under the EU Common Security and Defence Policy. The EU Battlegroup is available for peacekeeping or peace enforcement missions, for humanitarian operations or in emergency responses in the EU region (European Union External Action, 2017). The CBRN detachment and the field laboratory personnel trained during 2007 and were on standby with the Nordic Battlegroup, which Sweden led and included Finland, Norway, Estonia, and Ireland, during the first half of the year 2008. The FDF provided CBRN capability with the deployable field laboratory detachment consisting of a command element and three Platoons (CBRN platoon, CBRN field laboratory platoon, headquarters and logistic platoon including CBRN medical squad) with analytical, decontamination, reconnaissance, sampling, firefighting and medical capabilities (Kinnunen et al., 2012).

Finland is a member of the North Atlantic Treaty Organization (NATO) Partners for Peace programme and participated in the NATO Response Force pool in 2012 with the NATO Operational Capability Concept programme evaluated and approved deployable CBRN field laboratory capacity. The field laboratory is built on a semi-trailer and consists of a biosafety level 3 (BSL-3) laboratory (B-LAB) and a chemical analysis laboratory (C-LAB). The CBRN Field lab has also adjoining protective tents equipped with air filtration systems, where the field hygiene, radiological, and nuclear detection capabilities are located. It can be transported by air, sea, or land and used for either defence or civilian purposes, to investigate deliberate use of agents, natural outbreaks of disease, or accidents involving hazardous CBRN materials (Kinnunen et al., 2012).

The air pressure in B-LAB is normally maintained in negative pressure levels during BSL-3 operation, but a positive pressure environment can be applied during a CBRN emergency for protecting the personnel (Maatela, 2012). The samples are transferred to the laboratory through a sample hatch, which is connected to a Class III BSC for inactivation and preparation. After the inactivation and purification step, the samples are transferred to an adjoining Class II BSC through a dunk tank containing disinfectant solution, and then to a working area for subsequent analysis. Waste is handled inside the B-LAB with an autoclave and the whole B-LAB can be decontaminated with a hydrogen peroxide vapour system if necessary. The analytical equipment include real-time qPCR and immunological analysers, and the laboratory is equipped with a freezer, refrigerators, centrifuges, spectrophotometer, and other small laboratory equipment needed for sample storage and preparation (Kinnunen et al., 2012; Matero, 2017; Mölsä, 2017).

The C-LAB can be operated under overpressure during a CBRN event or other demanding environmental conditions, such as heavy pollution or dust. The C-LAB includes GC-MS, ion-red, Raman, and ion mobility spectrometers, ion chromatography, spectrophotometry, differential scanning calorimetry, and X-ray fluorescence devices. Besides chemical warfare agent identification, toxic industrial compounds, explosives, illegal drugs, and environmental pollutants can be confirmed by the C-LAB. The field hygiene and radio-nuclear analytical capabilities complement the comprehensive analytical capabilities of the laboratory. Field hygiene refers to various devices and techniques such as rapid culturing of microbial indicator species for the analysis of food, water and environmental samples; and radio-nuclear capabilities include gamma and alpha spectrometers and handheld radiation screening devices. The Finnish mobile diagnostic CBRN field laboratory fulfills the requirements of the NATO standardisation agreement and has been fully evaluated and approved by NATO (Kinnunen et al., 2012; Matero, 2017; Mölsä, 2017).

The FDF personnel of the CBRN Field Lab are conscripted, selected, and well trained and qualified in their relevant fields of sciences. The CBRN Field Lab is operated by seven key personnel: the laboratory leader, two scientists in both the B- and C-laboratories, as well
as one in the field hygiene and in the radio-nuclear laboratories each. Additionally, the CBRN Field Lab personnel include the driver of the semi-trailer and a four-person sampling and identification of biological, chemical, and radiological agents patrol trained in forensic CBRN sampling. The personnel of the field lab can be composed of enlisted scientific personnel, such as in the aforementioned EU Battlegroup, or conscripts with scientific backgrounds, who also receive training related to CBRN defence. The operation and maintenance of the CBRN Field Lab is funded from the defence appropriation of the Finnish government.

2.3. UNMOVIC biological analytical laboratory

The United Nations (UN) has conducted non-proliferation activities related to CWMD under two major commissions. In 1999, the UN Security Council Resolution 1284 established UNMOVIC as a monitoring and verification body to verify Iraq’s compliance to disarm and eliminate WMD. After the First Gulf War, UNMOVIC continued to build on the experience of the United Nations Special Commission (UNSCOM), which UN Security Council Resolution 687 established in 1991, to conduct on-site inspections and oversee the destruction and removal of equipment and material (UNSC, 2006). As directed by the UN, Iraq was required to declare any prohibited activities and cooperate by permitting inspectors access to their facilities unconditionally. The basis for inspections included visiting sites such as academic universities, military sites, biotechnology centres, and other research and development sites. Inspection activities included auditing declared items that were suspected of research, development, and production activities and interviewing scientists and other personnel to confirm their work was legitimate. This activity required inspectors to collect information that was compared to earlier baseline assessments, which then would help shape follow-on visits to establish that pattern of knowledge.

Through UNSCOM’s lessons learnt and recommendations from the Amorim Panel in 1999, UNMOVIC continued UNSCOM’s multidisciplinary approach deploying small teams of chemical, missile, and biological experts from member nations to continue ongoing monitoring and verification. Tools such as satellite imagery and ground penetrating radar provided additional information to inspectors and intelligence data complemented the information for analysis. Regarding biological samples taken during inspections, UNMOVIC’s ability to screen samples in their biological analytical laboratory using immunoassays and qPCR provided powerful analysis tools. A network of external laboratories was standing by to receive and test samples for confirmation; however, sending bulk samples requires additional time and cost to result (UN, 2007). Sample collection had to be performed judiciously to consider technical as well as political issues to balance the inspection regime (i.e. only testing necessary samples to avoid creating mistrust). Using standard operating procedures for sample collection (liquid, solid, environmental swipes) and analysis was paramount. Samples were requested on-site and split with the Iraqis keeping one sample and UNMOVIC keeping the second sample for testing in their biological analytical laboratory and network of secondary confirmatory laboratories if needed. UNMOVIC performed 731 on-site inspections from November 2002 to March 2003 that resulted in testing 356 samples from several sites (United Nations Security Council, 2003).

2.4. Ebola mobile laboratories

During the 2014–2015 outbreak of EBOV response, the EU, South Africa, the Netherlands, China, the US, and others deployed over a dozen mobile laboratories across Sierra Leone, Guinea, and Liberia. These deployments included vehicle transported portable modular-type (either stand-alone or refurbished fixed laboratory spaces), container-type, and truck-based laboratories. The EU-funded Mobile Laboratory Capacity for the Rapid Assessment of CBRN Threats Located within and outside the EU (MIRACLE) consortium deployed various mobile laboratories through their partners including the Belgian light fieldable B-LiFE (Guinea, December 2014–March 2015), the EML (West Africa, March 2014–present), the German Bundeswehr light fieldable lab (Mali, December 2014), and the Canadian Public Health Agency Mobile Laboratory (Gala & Vybornova, 2015, 2016). The US and the Netherlands deployed container-type field laboratories and China and Russia sent truck-based mobile laboratories. Several mobile laboratories were deployed through the WHO and close coordination occurred among the laboratories and other international organisations supporting the ETUs (Chua, Cunningham, Moussy, Perkins, & Formenty, 2015).

The EU and South African Ministry of Health’s NICD deployed modular field laboratories. The EML is a modular field laboratory deployable within 72 h based on the Bundeswehr medical mobile laboratory concept that uses an inflatable tent system to house diagnostics capabilities for medical surveillance. Equipment and supplies are packed into rugged boxes that can be easily transported by air and truck (Wölfel
et al., 2015). The EML has four key elements: trained personnel, biosafety and biosecurity management, methods and equipment, and logistical support (7 × 4 m footprint). Biosafety equipment included a glovebox and personal protective equipment (coveralls, goggles, FFP-3 face masks); diagnostic equipment included qPCR, immunoassays, and light microscopy. The EML was deployed March 2014–May 2015, and the team tested over 5,800 samples. The NICD also established an Ebola mobile laboratory for diagnosis of EBOV in Freetown-Lakka, Sierra Leone. Their modular set-up, which included a portable negative pressure biological containment system, was staged in an existing fixed laboratory. Equipment and supplies were also packed and secured on pallets for air transport. In addition to the bioccontainment system, the operational areas included administration and communication, specimen receipt, serology and qPCR sample extraction, and other segregated areas to perform qPCR. A BSL-3 environment was maintained using personal protective equipment: suits, gowns, double-gloves, and powered air purifying respirators with full-face masks and hoods. The NICD Ebola mobile laboratory was deployed August 2014–June 2016 and tested over 11,000 clinical samples from blood and buccal swabs. Of these suspected EBOV cases, 2,379 samples (21.4%) were found positive by qPCR (Paweska et al., 2017).

The Netherlands and the US both deployed versions of containerised transportable diagnostic laboratories to support the Ebola response. The Dutch Ministry of Foreign Affairs provided three container laboratories: two placed in Sierra Leone and one in Liberia. Each was set up to support an ETU or hospital. Their configurations include a 20 (6.1 m) or 40 (12.2 m) ft. container that may be trailer mounted. The space included identical biosafety level 2 (BSL-2) laboratory suites designed for clinical virology diagnostics (Reusken et al., 2016). The US DOD provided three container laboratories and activated the first one in January 2015. Using earlier configurations of shipping containers for mobile laboratories, a US-based non-profit life sciences organisation (MRIGlobal) developed one version to support laboratory diagnostics and another for emergency patient transport (Van Der Horst et al., 2016). The version for laboratory diagnostics was designed, assembled, delivered to Sierra Leone and Guinea, activated and staffed to support continuous operations for processing up to 110 samples for Ebola (Roberts et al., 2015). This version included separate containers for decontamination and shower; sample receipt, inactivation, and extraction; master mix preparation and qPCR analyses; and command and communications functions (Coffin et al., 2016).

China deployed a truck-based Mobile BSL-3 laboratory to Sierra Leone to support diagnosis of EBOV. Three container vehicles comprised this laboratory that included main container (L × W × H: 9.1 m × 2.4 m × 2.9 m), auxiliary container (same size), and command container (L × W × H: 6.3 m × 2.4 m × 2.1 m). Laboratory equipment included qPCR and BSCs. The laboratories were powered by alternating two 200 kW diesel generators (Chen et al., 2015; Zhang et al., 2017). Russia also deployed a truck-based mobile laboratory to Guinea under their Rospotrebnadzor’s (Federal Service for Surveillance on Consumer Rights and Human Wellbeing) Specialized Antiepidemic Unit (SAEU). The Rospotrebnadzor was formerly known as the Sanitary and Epidemiologic Service and is tasked to administer the modern AP institutes, which have SAEU mobile assets (McNamara et al., 2013; Russian Ministry of Finance, 2014; UNOG, 2016, 2017).

3. Comparing and contrasting the CWMD and public health preparedness missions

The CWMD and public health preparedness missions are distinct, and their approach to planning and coordination differs according to deployment and response. While the CWMD missions have common objectives to detect, identify, and prevent any WMD incidents, protect the warfighter, and ensure force protection, the public health preparedness mission is to contain and end the spread of an infectious disease outbreak while providing treatment to those in need. As an example of the latter, the main objectives of the Ebola response mission were to reduce turnaround time for diagnostic specimens (WHO target within 24 h) by providing qPCR detection capability, and personnel biosafety equipment and detection assays to better ensure treatment for infected individuals.

The respective missions may share similar needs for capabilities and resources while facing the same challenges. A tactical logistic planning method, the Military Appreciation Process (MAP), has been applied to field laboratory deployments (Inglis, 2015). MAP is a collaborative plan that brings together the commander’s intent with common situational awareness among the team, it is practised as doctrine by the Australian Army, and is equivalent to NATO’s Operating Planning Process and the US Military Decision-Making Process (Hoskin, 2009). For a field laboratory deployment, MAP relies on communicable disease intelligence from an outbreak to influence the just-in-time planning steps (mission analysis, course of action development, assessment,
and decision and execution) whereas consultative planning methods are used more often in public health preparedness (Inglis, 2015). A recently developed public preparedness logic model focuses on capacities, response capabilities, and objectives that target cross-border threats among EU member states. Our article is presented in accordance with their list of functions: legal and economic measures (e.g. national acts, mandates, and funding authorisations), operational measures (e.g. coordination, planning, and training), and social capital (networks, partnerships); and capabilities such as detection and assessment (Stoto, Nelson, Savoia, Ljungqvist, & Ciotti, 2017).

For the CWMD missions, the respective national acts and mandates described earlier set forth the organisational and funding structures for implementing operations and capabilities. For a public health preparedness response, often the organisational structure is set up, but a funding authorisation is needed to activate it. While the UNMOVIC case history was related to a CWMD mission, it had an organisational structure that the UN stood up as a response. The capabilities and funding compared below also describe notional budgets for workforce, equipment, and future sustainment costs.

3.1. Laboratory capabilities

The US National Guard CSTs and FDF deploy mobile capabilities which are both equipped to receive and analyse samples for chemical and biological threats using common detection technologies such as GC-MS and qPCR, respectively. The UNMOVIC biological analytical laboratory was also outfitted with some of the same chemical and biological detection and identification equipment and assays as the CST and FDF mobile laboratories. Detecting biological material is more complicated than nuclear or chemical material due to the complex nature of the sample material and the fact that molecular diagnostics are based on the presence or absence of that specific nucleic acid (e.g. DNA from bacteria or RNA from viruses). Accurate and rapid detection and identification of Ebola viral RNA from clinical samples requires specific sample preparation and molecular methods such as qPCR and biosafety equipment to protect laboratory workers. All field laboratories in Sierra Leone were equipped with qPCR for detection of EBOV with variations in equipment platforms and specific biosafety controls (Zhang et al., 2015). Testing costs for samples performed in a mobile or field laboratory are often high, for example, WHO estimates during recent Ebola outbreak responses are at US$100 per sample (WHO, 2017).

3.2. Personnel

The CWMD missions have far-reaching scope as related to the battlefield; for example, a CST comprises 22 full-time Air Force or Army personnel. The ALS is staffed by an officer and an enlisted operator who are responsible for completing all laboratory functions. While the US National Guard CST comprises volunteer personnel, the Finnish CBRN Field Lab relies on conscription where specialists are selected and qualified. UNMOVIC recruited and employed experts as permanent UN staff. In addition, UNMOVIC trained additional experts and worked to maintain a roster of over 300 trained experts. However, since their response team is not active unless a member state or the UN Security Council requests assistance, their response depends on readiness of the qualified, external workforce. The public health preparedness mission is similar; for example, qualified volunteers who were interviewed and assessed from diagnostics laboratories staffed the Dutch lab and received training to support the 2014 EBOV outbreak response mission (Reusken et al., 2016). The Germans also provided training modules to prepare personnel (Wölfel et al., 2015), while the US DOD mobile diagnostic laboratories were also staffed with volunteers recruited internally. Pre-deployment training included laboratory management, diagnostic testing, and biosafety and biosecurity. Various international agencies recognised the requirements for emergency evacuation and physical security of personnel in order for deployments to occur (Gala & Vybornova, 2015; Zhang et al., 2017). Ensuring emergency evacuation and safe treatment of personnel was also paramount in the event of staff contracting Ebola during deployment.

3.3. Readiness: laboratory proficiency training

Operational readiness and maintaining current equipment and methods are key areas for investment. Technical proficiency of the two CST ALS operators is sustained by monthly receipt and analysis of unknown proficiency analytical test samples from the US DOD Defense Biological Product Assurance Office, an agency formerly known as the Critical Reagents Program (US DOD CBD, 2017). Proficiency sample test results are reported monthly and serve to provide performance feedback to the various ALS teams as well as to assist the CST programme in meeting ISO 17025 standards for its mobile laboratory operations. As aforementioned, each CST team undergoes a mock external evaluation every 18 months that includes provision of simulant biological and chemical samples for...
analyses and reporting in the ALS. This evaluation also involves participation of external public health and first responder partners to maximise communication, interoperability, objectives, and value.

The technical and operational capabilities of the Finnish CBRN Field lab are evaluated annually in national and international exercises. The detection capabilities have been designed based on NATO AEP-66 manual and STANAG 4632: Deployable CBRN Analytical Laboratory standardisation agreement. The biological agents to be detected have been selected based on the standards and agreements as well as the US CDC’s select agents and toxins list. The analysis methods for detection and identification of these select agents have been developed using real-time qPCR. The target areas for each analyte have been carefully selected based on literature and sequence analysis where the analytical sensitivity and specificity have been thoroughly tested against multiple microbial strains. The qPCR assays are also validated with either samples containing the target agent or with environmental or clinical samples spiked with the target microorganism if samples are unavailable. Alternatively, mock samples containing powdery substances simulating ‘white powders’ can be used for training purposes for both the sampling team and the analysis laboratory (Matero et al., 2011).

Unknown samples that may contain biological, chemical, radiological, or explosive agents or so-called mixed samples are perhaps the most challenging ones. The unknown hazards are taken into consideration throughout the analytical chain and protocols for mixed samples have been developed and evaluated for the CST ALS and the Finnish CBRN Field lab, respectively. The ongoing task is to take into account new and emerging threats and to reduce the time from sample to result. The development of faster and simpler analysis methods, such as used also for point-of-care devices, and the advancement of rapid and small sequencing equipment may make it easier in the future to detect and identify new or modified biological agents. At present, the development and verification of a new laboratory developed real-time qPCR assay for a new analyte will take a few months and requires skilled and experienced personnel to be available for the development work.

3.4. Comparison of cost estimates

Direct comparison of operational and sustainment costs for different mobile and field transportable systems is challenging. Different staffing levels, selection of equipment and assays, and the potential to leverage existing logistics, maintenance, and purchase arrangements will all dramatically impact start up and operating costs. As part of logistical planning, it is important to consider that these costs should all be included in the planning of a mobile or field transportable capability.

Stand-up costs, related to initial equipment purchase, staff training, and vehicle outfit, can be readily estimated during the planning of mobile laboratory capability. Annual sustainment costs, based on planned staffing levels and drills, can also be readily quantified based on the organisation’s parameters to maintain required readiness. Additional cost for operational budget on laboratory deployment should be considered in order to support additional staffing needs and the consumables and reagents used during testing in a response situation. During training and drills or exercises, detailed records of reagent and consumable use should be documented. This information, in addition to the number of mock samples tested, can be used to develop simple models of usage rates for test kits, gloves, tubes, and other consumable items. Such models can be used as future templates to forecast needs based on the anticipated mission profiles for a given laboratory (Section 3) which will then inform budgeting and purchasing requirements.

Operational costs can be minimised if existing salaried staff members are allocated to the mobile unit; however, in an extended deployment, there is likely to be a need to rotate personnel. Similarly, it may be possible to draw reagents from existing laboratory stocks and back fill items, which does not remove the need to purchase items but does reduce concerns over the shelf life and storage of items if they are stockpiled solely for field use. Fiscal readiness is a critical component impacting the utility of a mobile of field transportable laboratory; if deployment costs cannot be met, then the value of such systems is greatly diminished. We present information on operational (deployment), annual sustainment, and initial stand-up costs for ALS as an illustrative example.

3.4.1. Operational costs of a CST ALS

Operational costs for equipment and consumables are likely similar for CWMD and infectious disease outbreak response missions; however, the laboratory platforms deployed in response to recent EBOV outbreaks featured more equipment, more staff, and significantly higher reagent use than expected for a typical CST domestic homeland security mission. The CSTs’ budget for two ALS mobile laboratories is at US$232,000 each, discussed further in Section 3.4.3. The estimated annual CST ALS operational costs include operator
salaries and benefits, laboratory reagents and consumables, and equipment depreciation and warranties (The IAB, 2017). Personal protective equipment, laboratory and test consumables and reagents, which often have a shelf life, pose additional costs to be accounted. CST programme-wide funding is also required for equipment spares, maintenance, warranties, and depreciation. In contrast, the EML asset mobilised for the most recent EBOV outbreak response estimated that their total equipment for the Ebola field deployment cost US$176,000 (£150,000) and that container or truck-based platforms cost 10 times more (Wölfel et al., 2015).

### 3.4.2. Annual sustainment costs of a CST ALS

Sustainment costs vary widely depending upon the scale of an outbreak response and the types of testing to be performed, and whether a deployable laboratory platform is used for ongoing (military defence assets) or recurring missions (singular response situations such as the aforementioned EBOV platforms). It is important that mobile laboratories be well-stocked with supplies and test reagents prior to deployment; due to the nature of the missions and the remote locations where this capability is most useful, equipment maintenance, personnel training, and resupply of reagents and consumables can be challenging. When a mobile laboratory is on standby or in a training status, consumables and supplies must be used in drills and exercises to maintain readiness, and care must be taken to replace expired or soon-to-be expired items. With these factors in mind, we believe that it is reasonable to assure that consumable items have a minimum of 3 months shelf life remaining to be considered ‘fit for purpose’ when stocking a mobile laboratory as sufficient time should remain to account for deployment duration and the uncertain length of resupply timelines. The CST ALS annual sustainment costs include travel funds for operator training, salaries, and housing and subsistence stipends in addition to the reagents and consumables discussed above. In contrast, laboratory staff for international disease outbreak missions are often extracted from fixed laboratory settings in hospitals and universities and draw financial support from those institutions when not in response mode.

### 3.4.3. Stand-up costs for a CST ALS

CST ALS stand-up costs include initial equipment acquisition and personnel training, funds for equipment warranties and depreciation, reagent and consumable acquisition and replenishment, and payment of personnel salaries and stipends. CSTs have a recommended equipment type that outfits each ALS mobile laboratory vehicle and a two-person staffing plan that only varies with specific military rank of the operators in each CST. Variation in forecasting stand-up costs for mobile and transportable laboratories depends upon the size of platform, number of operators, equipment selection, and supporting reagent and consumable item needs. In all cases, logistical challenges include repair and replacement of equipment such as maintaining certification of BSCs, all of which can be difficult to perform in remote locations. BSCs provide primary containment and have stringent testing and certification requirements that can be challenging to meet even under ideal conditions such as domestic homeland response missions. One training model implemented in Southeast Asia involved a qualified certifier providing initial training to staff who were accredited following completion and then provided close mentoring to new trainees (Whistler, Kaewpan, & Blacksell, 2016). There is no singular approach towards solving the BSC certification challenge but it is one that must be addressed for CWMD and infectious disease outbreak and public health preparedness response assets alike.

Regarding the Ebola response, transitioning resources from an outbreak response to more local use is important to sustain capability. In some mobile laboratory deployments, assets and equipment were donated and turned over to partner country institutes (Coffin et al., 2016; Paweska & Van Vuren, 2015). Testing for endemic infectious disease such as malaria complements the Ebola diagnostics and requires continuous training of local scientists. Additional training funds were invested to train scientists at partner country institutes so that their personnel were qualified to carry on operations. To conclude the cost discussion, all organisations experience personnel turnover and will incur costs related to workforce development and new staff training that are not already addressed.

### 4. Recommendations and lessons learnt

At the outset of this examination, we posed that a CWMD mobile and transportable laboratory model is suitable for use in planning an infectious disease outbreak and public health preparedness response. While the mission objectives are different, there are several key aspects and considerations that are common requirements: operator safety, training, certification and maintenance of proficiency; laboratory equipment operation, certification, and maintenance; laboratory
data and sample integrity, storage, and sharing; and unit cross-training and interoperability with established, local organisations.

To reinforce existing CWMD national acts, mandates, and a recent public health preparedness logic model, we further pose that establishment of select, key standards of approach and means of accomplishing the above are critical tasks given the number of agencies, countries, and regions that are developing and fielding mobile and transportable laboratories. Such detailed approaches, standards, and models have been proposed at the national and international levels (The IAB, 2017; Gala & Vybornova, 2015, 2016; Inglis, 2015; Stoto et al., 2017), but still need further coordination, communication, and harmonisation. The MIRACLE project, which concentrated on the needs and operations of EU CBRN Mobile Laboratories, recommended the coordination between EU member states to support the harmonisation and standardisation of different concepts of mobile laboratories according to applications, sustainability, development of the user requirements, as well as the inter-laboratory exercises and operational deployment. We propose further actions to better establish international coordination among EU, NATO, UN, and WHO such as coordination and dissemination of standards compendium; establishment of mobile and transportable laboratory units to access standards, organisational points of contact, mission summaries, and lessons learnt so that all future deployments of such assets, regardless of the source of the response, will be better standardised with regards to personnel safety and coordination of operations. While each nation must continue to stand up and resource mobile and transportable laboratory assets in their own manner, establishment and sharing of key guidelines and standards at the international level will better unify the CWMD and the infectious disease outbreak and public health preparedness response communities.

Acknowledgments

This article was written without any funding. The authors thank the reviewers and editors for their critique and insights. Special appreciation to Lance Presser for his review regarding the Ebola deployments.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Buchalter, A.R. (2007). Military support to civil authorities: The role of the department of defense in support of homeland defense. Retrieved from the Library of Congress website https://www.loc.gov/rr/frd/pdf-files/CNGR_Milit-Support-Civil-Authorities.pdf

Chen, Z.L., Chang, G.H., Zhang, W.Y., Chen, Y., Wang, X.S., Yang, R.F., & Liu, C. (2015). Mobile laboratory in Sierra Leone during outbreak of Ebola: Practices and implications. Science China. Life Sciences, 58, 918–921.

Chua, A.C., Cunningham, J., Moussy, F., Perkins, M.D., & Formenty, P. (2015). The case for improved diagnostic tools to control ebola virus disease in West Africa and how to get there. PLoS Negl Tropical Diseases, 9(6), e0003734.

Coffin, J., Roberts, D., McCampbell, D., Carter, G., Haney, P., Bogan, J., … Yeh, K. (2016, February). Rapid deployment and operation of Ebola viral disease diagnostic laboratories in West Africa. Oral presentation at the ASM Biodefense and Emerging Diseases Research Meeting, Crystal City, VA USA.

Defense Against Weapons of Mass Destruction Act of 1996, Pub. L. No. 104-201,110 Stat. 2714. Sections of 50 U.S.C.
Retrieved from the Congress.gov web site. https://www.congress.gov/bill/104th-congress/house-bill/3730

Department of Defense Plan for Integration of a National Guard Reserve Component Support for Response to Attacks using Weapons of Mass Destruction. (1998). Retrieved from the Defense Technical Information Center web site: http://www.dtic.mil/docs/citations/ADA341853

Diarra, B., Safornez, D., Sarro, Y.D.S., Kone, A., Sanogo, M., Touranka, S., … Rosenke, K. (2016). Laboratory response to 2014 Ebola virus outbreak in Mali. The Journal of Infectious Diseases, 214(suppl_3), S164–S168. Retrieved from website https://academic.oup.com/jid/article/214/suppl_3/S164/2388102

Edgewood Chemical and Biological Center. (2008). Edgewood Chemical Biological Center’s CBRNE mobile laboratories team. Retrieved from website https://www.ecbc.army.mil/ip/brochures/ecbc_MLK_brochure.pdf

European Union External Action: EU Battlegroups. Bruxelles. (2017). Retrieved from EU website https://eeas.europa.eu/headquarters/headQuarters-homepage/33557/eu-battlegroups_en

Flint, M., Goodman, C.H., Bearden, S., Blau, D.M., Amman, B.R., Basile, A.J., … Dodd, K.A. (2015, 1 October 2015). Ebola virus diagnostics: The US Centers for disease control and prevention laboratory in Sierra Leone, August 2014 to March 2015, The Journal of Infectious Diseases, 212(suppl_2), S350–S358.

Gala, J.L., & Vybornova, O. (2015). Mobile laboratory capacity for the rapid assessment of CBRN threats located within and outside the EU. Retrieved from website https://sites.uclouvain.be/md-ctma/public/D6_3_recommendations.pdf

Gala, J.L., & Vybornova, O. (2016). Final report summary – MIRACLE (Mobile Laboratory Capacity for the Rapid Assessment of CBRN Threats Located within and outside the EU). Retrieved from website http://cordis.europa.eu/result/rcn/176295_en.html

Grolla, A., Jones, S.M., Fernando, L., Strong, J.E., Stroher, U., Moller, P., … Feldmann, H. (2011). The use of a mobile laboratory unit in support of patient management and epidemiological surveillance during the 2005 Marburg Outbreak in Angola. PloS Negl Tropical Diseases, 5(5), e1183.

Hoskin, R.H. (2009). The ghost in the machine: Better application of human factors to enhance the military appreciation process. Canberra: Land Warfare Studies Centre. Retrieved from army.gov.au website https://www.army.gov.au/sites/g/files/net1846/f/sp316_ghosts_in_the_machine-rupert_hoskin.pdf

Inglis, T.J.J. (2015). Adapting the mobile laboratory to the changing needs of the Ebola virus epidemic. Journal of Medical Microbiology. 64, 587–590. Retrieved from microbiologyresearch.org website http://www.microbiologyresearch.org/docservlet/fulltext/jmm/64/6/587_jmm00063.pdf?expires=1509131759&id=id&accname=guest&checksum=6E48DBAA25B2441F972ED32F4BE583B

Joint Program Executive Office (JPEO) fact sheet on the Common Analytical Laboratory System (CALS). (2014). Retrieved from JPEO website https://jacks.jpeocbd.army.mil/Public/FactSheetProvider.aspx?productId=373

Kinnunen, P.M., Haataja, T., Hemmila, H., Maatela, P., Theo, K., Elo, M., … Nikkari, S. (2012). Mobile diagnostic CBRN field laboratory: NATO evaluated Finnish design. Retrieved from researchgate.net website https://www.researchgate.net/publication/235575081_Mobile_Diagnostic_CBRN_Field_Laboratory_NATO_evaluated_Finnish_Design

Maatela, P. (2012). CBRN – Kentsitäjäkamaroi. Juhlakirja. Suomalainen NBC-symposiumi. CBRN-suojelun puolestta 20 vuotta. (CBRN Field Laboratory. Anniversary publication. The Finnish NBC Symposium. 20 years for CBRN defence). Retrieved from website http://www.nbcsfi.fi/spry/arkisto/NBC_juhlakirja_2012.pdf

Matero, P., Hemmilä, H., Tomaso, H., Piiparinen, H., Rantakokko-Jalava, K., Nuotio, L., & Nikkari, S. (2011). Rapid field detection assays for Bacillus anthracis, Brucella spp., Francisella tularensis and Yersinia pestis. Clinical Microbiology and Infection, 17, 34–43.

Matero, P.H. (2017). Identification of bacterial bioterror agents and pathogens by rapid molecular amplification methods (Published doctoral dissertation). University of Helsinki, Finland. Retrieved from Helda website https://helda.helsinki.fi/handle/10138/180148

McNamara, T., Platonov, A., Elleman, T., & Gresham, L. (2013). The human-animal inter-face and zoonotic threats: The Russian Federation approach. Biosecurity and Bioterrorism, 11(93), 185–195.

Melikishvili, A. (2006). Genesis of the anti-plague system: The Tsarist period. Critical Reviews in Microbiology, 32 (1), 19–31. Retrieved from NTI website http://www.nonproliferation.org/wp-content/uploads/cns-archive/antiplague/melikishvili.pdf

Ministry of Defence of Finland. (2008). Unofficial translation of the act on the defence forces. Retrieved from website: https://www.finlex.fi/en/laki/kaannokset/2007/en20070551.pdf

Mölsä, M. (2017). Rapid Identification of Selected Pathogens in Biothreat Preparedness (Published doctoral dissertation). University of Helsinki, Finland. Retrieved from Helda website https://helda.helsinki.fi/handle/10138/169646

Nepomnyashcha, N. (2017). Meningitis outbreak response: How a mobile laboratory helps saves lives. Africa Health, 16. Retrieved from website https://africa-health.com/wp-content/uploads/2017/07/8-eHealth-feature.pdf

Nisii, C., Vincenti, D., Fusco, F.M., Schmidt-Chanasit, J., Carbonnelle, C., Raoul, H., & Di Caro, A. (2016). The contribution of the European high containment laboratories during the 2014-2015 Ebola Virus Disease emergency. Clinical Microbiology and Infection. Retrieved from Clinical Microbiology and Infection website http://www.clinicalmicrobiologyandinfection.com/article/S1198-743X(16)30227-0/pdf

Paweska, J.T., & Van Vuren, P.J. (2015). Fourth report on south african ebola mobile laboratory activities in freetown – handover of the laboratory to the ministry of health and Sanitation Sierra Leone (Technical Report). Retrieved from researchgate.net website: https://www.researchgate.net/publication/280253577_Fourth_Report_on_South_African_Ebola_Mobile_Laboratory_Activities_in_Freetown-_Handover_of_the_laboratory_to_the_Ministry_of_Health_and_Sanitation_Sierra_Leone

Paweska, J.T., Van Vuren, P.J., Meier, G.H., Le Roux, C., Conteh, O.S., Kemp, A., … Du Plessis, D. (2017). South
African Ebola diagnostic response in Sierra Leone: A modular high biosecurity field laboratory. *PloS Negl Tropical Diseases*, 11(6), e0005665.

Reusken, C.B.E.M., Smit, P., Pas, S., Haagmans, B.L., Mulder, R., Postma, S., … Koopmans, M.P.G. (2016). Ebola virus laboratory response: The three Dutch Mobile laboratories in Liberia and Sierra Leone. *Clinical Microbiologic Infection Diseases*. https://www.oatext.org/pdf/CMID-SI-005.pdf

Roberts, D.P., Altmann, S.E., Stamper, P.D., Carter, G., Hegarty, R.E., McCampbell, D., … Coffin, J.M. (2015). The mobile laboratory experience: Perspectives on future disease surveillance and response in Sierra Leone. Oral presentation at the ASTMH Annual Meeting, Philadelphia, PA USA.

Rosenberg, B.H. (2007). A counter-bioterrorism strategy for the new UN secretary-general. Retrieved from the Acronym Institute for Disarmament Diplomacy website http://www.acronym.org.uk/old/dd/dd84/84bhr.htm

Russian Ministry of Finance. (2014). Russian contribution to the international development assistance in 2014. Retrieved from Russian Ministry of Finance website https://www.minfin.ru/common/upload/library/2015/10/main/Russian_contribution_to_the_international_development_assistance_in_2014.pdf

Stoto, M.A., Nelson, C., Savoia, E., Ljungqvist, I., & Giotti, M. (2017). A public health preparedness logic model: Assessing preparedness for cross-border threats in the European Region. *Health Security*, 15(5), 473–482. Retrieved from website http://online.liebertpub.com/doi/pdf/10.1089/hs.2016.0126

The InterAgency Board. (2017). Position paper: Bioterrorism preparedness & response. Retrieved from IAEM website http://www.iaem.com/documents/IAB-Bioterrorism-Preparedness-and-Response-Proposed-Model-18Jan2017.pdf

U.S. Department of Defense Chemical and Biological Defense Annual Report to Congress (2017). Retrieved from the Federation of American Scientists web site: https://fas.org/irp/threat/cbw/cbd-2017.pdf

U.S. Department of Defense National Guard Regulation (NGR) 500-3: National Guard Civil Support Team Management. (2011, May 9). Arlington, VA: National Guard Bureau. Retrieved from http://www.ngbpdc.ngb.army.mil/pubs/10/ang10_2503.pdf

U.S. Department of Defense press release, Weapons of Mass Destruction-Civil Support Team Certified for Guam and the United States Virgin Islands (2009, June 2). Retrieved from http://www.defenselink.mil/Releases/Release.aspx?ReleaseID=12713

U.S. National Defense Authorization Act (November 24, 2003), Retrieved from: https://www.gpo.gov/fdsys/pkg/PLAW-108publ136/pdf/PLAW-108publ136.pdf

United Nations. (2007). Disarmament 2007: Critical disarmament issues. Retrieved from website https://unoda-web.s3-accelerate.amazonaws.com/wp-content/uploads/loads/assets/HomePage/ODAPublications/AdhocPublications/PDF/NGOweb.pdf

United Nations Office Geneva (UNOG). (2016). The Experience of operating specialized mobile anti-epidemic units of Rosnostrobnadzor (Federal Service for Surveillance on Consumer Rights and Human Wellbeing). Retrieved from UNOG website https://www.unog.ch/80256EDD006B8954/ (httpAssets)(077A10D2C81F4169C1257FAF00437265/$file/SAEU-Russian+presentation+26.04.16.pdf

United Nations Office Geneva (UNOG). (2017). Establishing Mobile Biomedical Units Under the BWC: A Multipurpose Capability to Strengthen Collective Security Under the Convention Pursue its Humanitarian Mandate. Retrieved from UNOG website: https://www.unog.ch/80256EDD006B8954/ (httpAssets)/34D9E683F43E7769C125800B005D22B2/$file/SAEUTranslEng.pdf (22 October 2017)

United Nations Security Council. (2003). Thirteenth quarterly report of the Executive Chairman of the United Nations monitoring, verification and inspection commission in accordance with paragraph 12 of security council resolution 1284 (1999) (Report No. S/2003/580). Retrieved from website http://www.un.org/Depts/unmovic/documents/S-2003-580.pdf

United Nations Security Council. (2006). Summary of the compendium of the IPI’s proscribed weapons programmes in the chemical, biological and missile areas (Report No. S/2006/420). Retrieved from website http://www.un.org/Depts/unmovic/new/documents/compendium_summary/s-2006-420-English.pdf

Van Der Horst, K., Coffin, J., Roberts, D., McCampbell, D., Haney, P., Bogan, J., … Yeh, K.B. (2016, April). Successful application and use of modified shipping containers for laboratory diagnostics and emergency patient transport to support the ebola disease outbreak response in West Africa. Poster presented at 15th Medical Biodefense Conference, Munich, Germany.

Whistler, T., Kaewpan, A., & Blacksell, S.D. (2016). A biological safety cabinet certification program: Experiences in Southeast Asia. *Applied Biosafety*, 21(3), 121–127. Retrieved from website https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5053331/pdf/nihms819123.pdf

Wölfl, R., Stoecker, K., Fleischmann, E., Gramsamer, B., Wagner, M., Molkenthin, P., … Zöller, L. (2015). Mobile diagnostics in outbreak response, not only for Ebola: A blueprint for a modular and robust field laboratory. *Euro Surveillance*, 20(44), pii=30055.

World Health Organization. (2017). Retrieved from WHO website http://www.who.int/mediacentre/news/ebola/18-november-2014-diagnostics/en/

Yeh, K. (2010). Untitled. Unpublished notes. Microsoft Word File.

Yeh, K.B. (2017). Biosecurity Readiness for a Nonproliferation Mission: Responding to North Korea’s Biological WMD Threat. Unpublished work. Adobe Acrobat document file

Zhang, W.Y., Chen, Y., Kamara, A., Chen, Z., Chang, G., Wurie, I., … Liu, C. (2015). Field labs in action for Ebola control in Sierra Leone. *Infection Diseases Transactions Medicine*, 1, 2–5.

Zhang, Y., Gong, Y., Wang, C., Liu, W., Wang, Z., Xia, Z., … Guo, Z. (2017). Rapid deployment of a mobile biosafety level-3 laboratory in Sierra Leone during the 2014 Ebola virus epidemic. *PloSNegl Tropical Diseases*, 15(11 (5)), e0005622. Retrieved from PLoS website http://journals.plos.org/plosntds/article?id=10.1371/journal.pntd.0005622