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LIGHTWEIGHT CHEMICAL DETECTOR AS POSSIBLE EFFECTIVE DEVICE FOR CBRN DEFENCE EQUIPMENT OF TROOPS

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ABSTRACT

The CBRN detection indicates, by any means, the presence of a CBRN substance. One of the most important elements of this is the chemical detector. Detection of chemical warfare agents and toxic industrial materials is required for a timely warning of units. The equipment of CBRN reconnaissance organizations is a critical factor that fundamentally determines the ability of subunits. Thus, one of the technical pillars of the threat response can be considered the capability of CBRN reconnaissance instruments, including chemical detectors. In addition to the capacity of instruments for the detection and identification of chemical, biological and radioactive materials, their size and mass are also important factors for field application. When designing the equipment of CBRN reconnaissance subunits, it is important to create a detector collection suitable for the organization's application purposes. The author of the article presents the key elements of CBRN defence and highlights the development of tools that are based on IMS technology.

KEYWORDS: CBRN defence, CBRN reconnaissance, chemical detector, Ion Mobility Spectrometer

1. Introduction

The objectives of CBRN Defence may be grouped into five enabling components:

- Detection, Identification and Monitoring;
- CBRN Knowledge Management;
- Physical Protection;
- Hazard Management;
- Medical Countermeasures Casualty Care.

When using an CBRN weapon as well as in the event of nuclear or industrial disasters, large areas may become chemically and radioactively contaminated. More so, the use of Improvised Explosive Device as CBRN Dispersal Devices may produce a contaminated area. The danger of using various homemade explosive devices is also significant (Horváth & Ember, 2021). The detection, identification and monitoring activities executed by the relevant units are referred to as CBRN reconnaissance.

In order to protect the personnel of the units, it is necessary to quickly determine the presence of toxic and radioactive substances, the location of chemically and radioactively contaminated areas, and the expected actual consequences. For this reason, CBRN reconnaissance must be carried out by the subunits, which requires the necessary equipment and tools. In order to avoid harmful consequences, CBRN detectors are necessary to ensure an efficient and timely handling.

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Within CBRN reconnaissance, regarding the chemical detection activities, it is of key importance to determine firstly whether there is a chemical threat. Detection indicates the presence of a chemical warfare substance. However, in order to organize the defence, it is necessary to carry out the identification of the chemical agent, the delineation of the contaminated area and the monitoring of changes over time.

The three basic tasks of chemical reconnaissance are: detection, identification and monitoring.

Detection means the determination of toxic substances in the air, and it includes the following activities:

●announcing the start of a chemical attack, whereby it is required to either use the individual protective equipment or apply collective protection;

●indicating the end of chemical threat, whereby individual and collective protection measures are not required any longer and its application may be eased or even terminated;

●determining the quality (type) and quantity (concentration) of the toxic substance in question to support and confirm the implementation or discontinuation of certain regulations and the necessary calculations.

One of the most important parameter of detection are sensitivity. Sensitivity is characterized by either the amount of toxic substance that can be detected in a unit of mass, or the concentration limit relative to the sample size (the lowest level of concentration at which the substance is still detectable). The sensitivity level is determined by the toxicity of the given substance (Havai, 1999).

During the identification process, accurately determining the quality (type) and quantity (concentration) of the toxic (warfare) agents requires expensive, heavy tools with complex structures. Mass spectrometry (MS) instruments are excellent tools for the qualitative and quantitative determination of chemical warfare agents and other toxic substances. These devices are also commercially available either as a vehicle-mounted, portable equipment or as a laboratory tool.

Monitoring (control) is a continuous or periodic procedure of determining the presence of CBRN hazard. The chemical examination monitors and specifies the chemical contamination level of individuals, military or technical equipment, devices and other materials, objects, terrain, freshwater and provisions. Infrared spectroscopy devices used for monitoring air quality are generally suitable for the identification of chemicals.

A device called GASMET (Gasmet Technology, Finland), an FTIR analyser is capable of examining 25 compounds at the same time and it can identify the organic and inorganic components of the sample (Vágföldi & Földi, 2011).

Regarding the tasks of CBRN reconnaissance, it can be seen that different objectives can be associated with the reconnaissance activities carried out in different areas, so their achievement requires the use of instruments with different characteristics.

In this sense, detection primarily means the presence of CBRN threats, which demands the implementation of individual and collective protection regulations. Each squadron subunit shall possess the necessary equipment for basic level CBRN recce, monitoring, decontamination, medical care and collective protection. One of these equipment is the chemical detector.

Regarding the objective detection methods, the chemically based procedures are reliable and accurate. However, it should be noted that if there is a toxic (chemical warfare) agent in the air without any reagent in stock or its state of matter is not favourable for the reaction, then the detection may fail. A typical chemically based detector, Colorimetric Detection Tubes kit, shown in Figure no. 1, includes a given number of tubes.

Figure no. 1: *Chemical based detector*
(Source: Author)

However, different methods for the physically based detection of toxic substances offer a number of advantages, one of which is the rapid detection, which is an essential element in the process.

The presence of chemical warfare agents causes a change in the physical properties of air (e.g. electrical conductivity) and by detecting these changes, one is able to determine the presence, type, and concentration of toxic agents.

The main methods used for the physically based detection of toxic warfare agents include:

- Ion Mobility Spectrometry (IMS),
- flame photometry,
- photoacoustic imaging,
- infrared (IR),
- laser techniques used for testing absorption at specified wavelengths.

2. Ion Mobility Spectrometry in CBRN Reconnaissance

Because of their reliability, devices based on IMS technology are greatly utilised worldwide to detect chemical warfare agents. These tool also represent a significant asset at subunit-level within the armed forces.

The typical properties of detectors based on ion mobility spectrometry, such as simple handling and fast, real-time detection, are an advantage when using them (Epure, Grigoriu, Dinescu, & Toader, 2009).

Although ion mobility spectrometers may be uncertain when evaluating complex samples, they are rather reliably detecting nerve and blister type of chemical agents.

These devices provide sufficient information for the subunits to perform the CBRN defence tasks, they are easy to use and do not require special technical knowledge. More so their acquisition costs are lower compared to the acquisition of high-efficiency detectors (which are suitable for the specific CBRN defence units).

Ion-mobility spectrometers are using either α and β ray for ionising the sampled air intake, then the generated charges will be moved with an electronic impulse, or alternate frequencies for manipulation. This method basically benefits from the mobility of charged particles due to their different masses. These devices are equipped with IMS cells that are able to detect and identify nerve (G) agents and blister (H) agents.

The essential point of the technology is that the gas mixture is transferred from the environment into the device by a pump. After that, the mixture traverses a drift tube where the particles and molecules will be ionised. Ions of different mass numbers then arrive at a negatively prestressed grid. Some of these ions will be recombined while the majority of them will be accumulated at the grid. Because of the positive impulse on the grid, ions of higher mass number will reach the detector slower, while the ones with lower mass number will complete the same journey much faster. The number of separate ion formations arriving into the detector will be identical with the different mass number ions that are forming the ionized gas mixture. The ionic current is then conducted to an extremely high value resistor. The voltage across the resistor is processed after amplification (sampling, A/D conversion, etc.). The device then stores in its memory the amount of time elapsed since the start, as these are the characteristics of a given ionic mass. As a general principle of identification, all possible material types for all possible time intervals will be pre-stored in the internal library of the device. Since each data can be linked to either an atom or a molecule, the identification may be executed by running a specific software (Kovács, 2006).

2.1. Chemical Agent Detector (CAM)

The worldwide are regularly using a chemical agent monitor, shown in Figure no. 2, device that detects and discriminates between vapours of nerve and blister agents and displays the relative concentration and level of threat.

Figure no. 2: *CAM chemical agent detector*
(Source: Author)

The CAM detects vapours of toxic chemical agents in the environment and automatically rings the alarm. A special, remote alarm may also be attached to the device in order to ensure that the warning signal is heard at a distant location as well, such as in field conditions. The device does not only confirm the presence of G (nerve agents) or H (blister agents) types of chemical warfare agents, but also identifies the threat level of the vapour concentration.

The CAM device detects the nerve and blister agents using and ionisation chamber that is integrated with a Ni-63 radioactive source. The pump takes a sample from the air, then this sample is transferred to the ionisation chamber where the isotope breaks it down into ions. Their quality and quantity is compared with the data of the built-in microchip in order to determine the type and hazard of the toxic warfare agent (Gamma Műszaki Rt., 2001).

The CAM (the first model) is a single-chamber device, thus, it is only able to detect one type of agents at the same time (either G or H) therefore, and users are required to switch with a button, when needed. The device is not capable of detecting toxic industrial chemicals (TICs).

With all its characteristics, CAM has proven to be suitable for chemical detection activities and for the identification of chemical contamination level of personnel, equipment, weapons, fighting vehicles, facilities or terrain. It can also be used to control the effectiveness of decontamination and to monitor air pollution.

Nevertheless, because of recent technical developments, more efficient IMS devices are available already in the field of CBRN defence.

2.2. New IMS Technology to Detect Toxic Industrial Chemicals and Toxic Warfare Agents

Regarding the new generation of IMS technologies, a significant progress has been made in 3 main areas. Firstly, the device does not utilize anymore a radioactive source, secondly, the size and the weight of the device have been reduced and lastly, the range of detectable substances has been increased.

Relatively small devices with a nuclear radiation source get lost more frequently.

According to the 2022 report of the International Atomic Energy Agency (IAEA) there were 3928 events reported in connection with radioactive materials between 1993 and 2021, of which 320 events were unauthorized possession and connected crimes. 1034 incidents for which there is insufficient information to determine if it is related to trafficking or malicious use. The sources are usually portable devices and due to their mobility they can be easily stolen or lost (IEAE, 2022).

Based on the above, it is worth to consider to apply IMS devices that do not require a radiation source, especially at locations where the device is more exposed to external threats.

2.3. Lightweight Chemical Detector (LCD) 3 series

Built on ion mobility spectrometry techniques, the LCD 3 Series models, shown in Figure no. 3, are lightweight, use non-radioactive ion mobility spectrometry technology battery-powered devices, that are suitable for detecting toxic warfare agents and toxic industrial compounds in the air. They are characterized by both low space requirements and low-power consumption.

Figure no. 3: *LCD 3.2 chemical agent detector*
(Source: Author)

The LCD 3.2/3.3 is a small, handheld, portable device that can easily be fastened to clothing to give a hands free detection capability. On detection of chemical agent, the device gives an audible and visible signal. The 3.3 version, shown in Figure no. 4, also has a liquid crystal display. The device is easy to use without any calibration or complex setup. The detector can also be operated while inside the carrying pouch. A survey nozzle may be attached to the detector when there is a need to investigate a particular carriage, supplies or other areas and locations. The memory of the device is capable of storing up to 72-hours of operational data for future analysis. With the RS232 interface, the detector may be connected to a personal computer that allows further analysis and also software update (Smiths Detection, 2022).

Figure no. 4: *LCD 3.3 light chemical agent detector*
(Source: Smiths Detection.com)

It may be used either as a mobile, portable or a fixed device. The LCD 3.3 may be used to detect the following chemical warfare agents and toxic industrial chemicals:

– Regarding the detection of chemical warfare agents, the device identifies nerve agents (GA, GB, GD, GF, VX, etc.) as well as blister agents and other generic toxic agents.

– In terms of toxic industrial chemicals (TICs) detection, the device simultaneously detects ten out of thirty selected substances (Smiths Detection, 2022).

This functionality is important for both the protection of subunits and interoperability, which is vital on subunit level. One of the determining capabilities of the future individual equipment system is to have elements that may be integrated into a network. Hungarian research has shown that the LCD chemical detection device could be integrated into an individual equipment system (Gácser, 2008).

3. Comparison

Detection/identification characteristics of the chemical decector are important in terms of efficiency. CAM cannot identify a chemical warfare agent, it can only specify the class of agent. CAM is not able to detecting simultaneously both class of agent, the mode must be selected manually. The LCD series is capable of simultaneously detecting nerve and blister agents. Furthermore, LCD 3.2/3.3 is capable of detecting toxic industrial materials.

For CAM the minimum detectable level for agent HD is 0,16 mg/m^3 and for agent GA is 0,11 mg/m^3 at ambient temperatures and 50% relative humidity. At ambient temperatures and 90% relative humidity detectable level for agent HD is 0,15 mg/m^3 and for agent GA is 0,03 mg/m^3 . (Longworth & Ong 2001)

For LCD the minimum detectable level for agent HD is 2 mg/m^3 and for agent GA is 0,1 mg/m^3 at ambient temperatures regardless of relative humidity (Smiths Detection, 2022)

The detection sensitivity to chemical agents of IMS detectors are different as showed in the following figure.

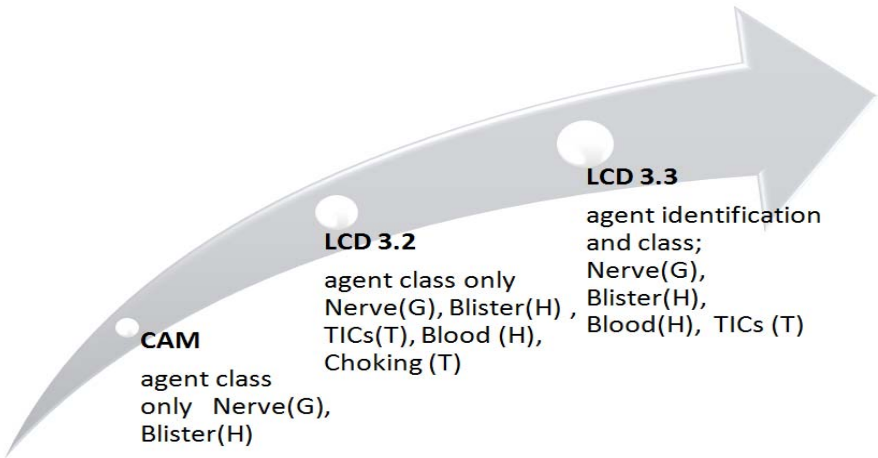

Figure no. 5: *Detection capacity of CAM, LCD 3.2 and LCD 3.3 detectors*
(Source: SmithsDetection.com, edited by Berek)

Size and weight clearly define applicability. Considering the transportation of the device, every amount of weight loss has already a significant benefit for military units. In terms of its application, the effect is similar because during chemical detection and inspection activities, the weight of the device – when lifted or held – indirectly affects the efficiency through the load it has on the user. The size and weight comparison of the devices in question are showed in the following figure.

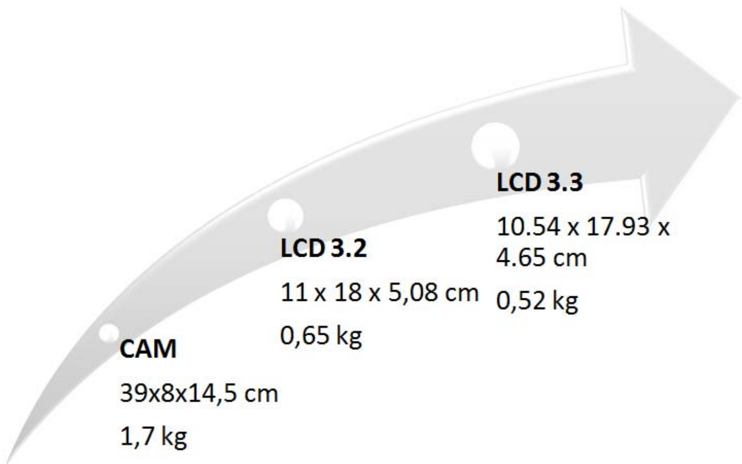

Figure no. 6: *Size and weight comparison of CAM, LCD 3.2 and LCD 3.3 devices*
(Source: SmithsDetection.com, edited by Berek)

Another important characteristic of the detector is its anticipated battery lifetime. When using the detector, the lifetime of the rechargeable or AA size battery is critical. Certainly, a long operational time and an easy, quick change of the power supply are required.

It is important to highlight that the commercially available detectors of the LCD series are operated either by the standard alkaline AA batteries or by rechargeable batteries. On the other hand, the CAM devices use only rechargeable battery that has a particular design and requires its specific charger. The following table illustrates and compares the lifetime of the devices in predefined temperature.

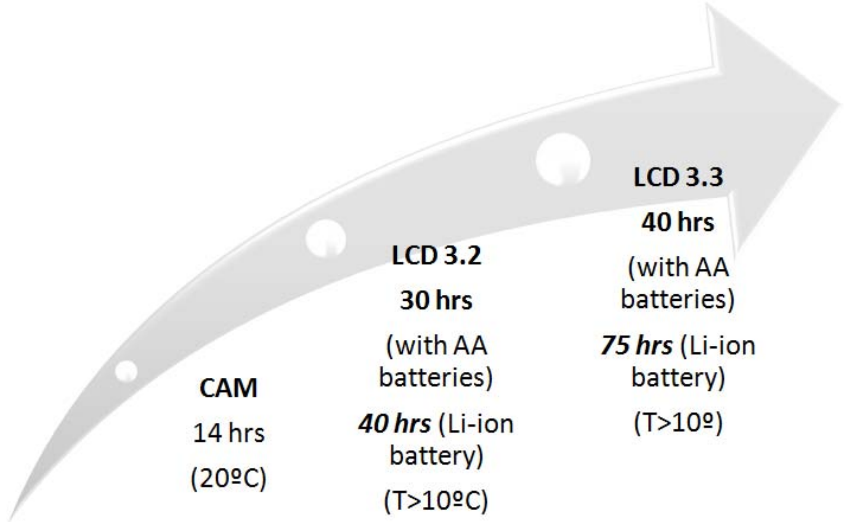

Figure no. 7: *Anticipated operational lifetime of CAM, LCD 3.2 and LCDE 3.3 dete*ctors
(Source: SmithsDetection.com, edited by Berek)

The operating temperature range is also considered decisive. Currently ongoing operations are often conducted in extreme weather – as well as temperature – conditions. Because of this, the operating temperature range of each chemical detection device must be extended to make sure that they are still functioning under such conditions. IMS detectors are capable of operated in different climatic conditions, as showed in the following figure.

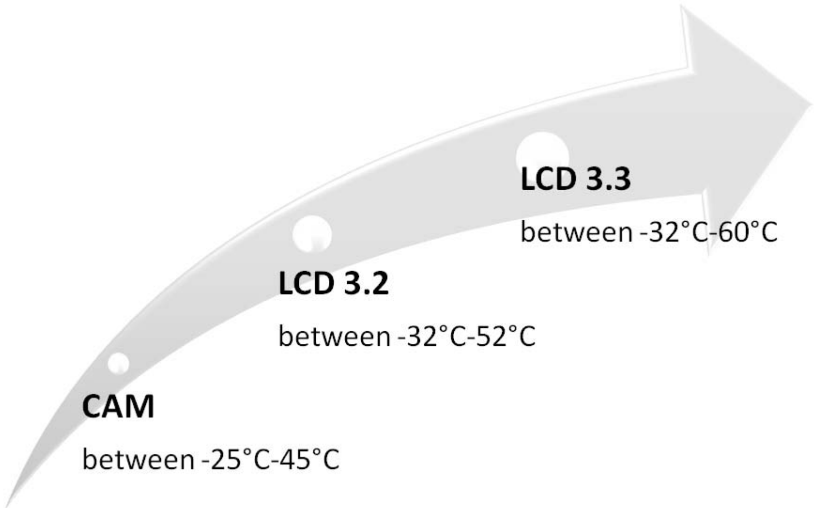

Figure no. 8: *Operational temperature range of CAM, LCD 3.2 and LCD 3.3 detectors*
(Source: SmithsDetection.com, edited by Berek)

4. Conclusions

The recent changes in global security policy and the new types of challenges that CBRN defence also faces are requiring adequate responses from the constantly evolving defence sector as well. Critical infrastructures are considered especially vulnerable. Effective control, preparedness or, even a possible prevention by modern tools are essential (Kovács, 2012).

CBRN defence capabilities are undergoing a radical change as well, notably through the development and implementation of new, cutting-edge and certainly more effective devices.

Within the NBC detection procedures, IMS-based devices (CAM, GID3) are among the most popular physical detection methods to identify toxic warfare agents and toxic industrial chemicals. Because of their favourable characteristics such as fast detection, reliable operation and easy, user-friendly handling, they are the preferred tools of military units. As a result of recent developments, some features of the new generation devices have improved to such an extent that they definitely deserve attention.

Previously observed difficulties such as battery substitution, narrow range of detectable materials, and physical dimensions (dimension, weight) have been eliminated in the new, LCD type of devices. The measurement principle is still IMS technology, however it does not contain a radioactive radiation source, hence, it is also a beneficial upgrade for safety reasons. A wider range of detectable toxic warfare agents and toxic industrial chemicals as well as their simultaneous identification represent a significant step forward in the timely alerting of personnel and the implementation of appropriate CBRN defence measures. At the same time, reducing the size and weight of the device facilitates its applicability from a user point of view, which also indirectly affects the detection efficiency.

In addition to the abovementioned benefits, both versions of the LCD may be easily integrated into the on-board system of various combat vehicles, providing the vehicle with relatively rapid chemical alarm capability, which helps to protect the operating personnel from both toxic warfare agents and toxic industrial chemicals. The remote control option also increases flexibility. It can be used either as a mobile, portable or a fixed device. It may also be connected to a computer or network via USB or through the RS-232 protocol with constant, real time detection of toxic warfare agents and toxic industrial chemicals.

In addition to the challenging development of doctrines, policies and procedures, the modernisation of CBRN detection tools, by understanding potential threats, remains a key element in maintaining defence capabilities.

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