DESIGN OF MINE WARFARE DIVING TECHNOLOGY. STANDARDISATION REQUIREMENTS

Ryszard Kłos

Naval Academy in Gdynia, Poland

ABSTRACT

This article is consecutive in an unintended series on diving technology design [1,2]. Requests for a detailed account of the *strategy*[1] employed and its compatibility with methodology[2] suggest that the earlier description of it proved too general [3]. In the first part, on the example of diving technology used in mine warfare systems, its design is briefly discussed in the light of meeting NATO Standardisation Organisation requirements. The article refers to the elements of the methodology[3] applied in the work on the Nx-SCR CRABE SCUBA diving technology on the basis of the national theory[4] containing primarily deterministic methods[5] for modelling semi-closed SCR breathing systems[6], enabling reliable research with previously unavailable efficiency [4,5].
Keywords: Aparat nurkowy o półzamkniętym obiegu czynnika oddechowego/Semi-Closed Circuit Rebreather, Technologia nurkowania/Diving technology.

ARTICLE INFO

PolHypRes 2022 Vol. 78 Issue 1 pp. 7 – 30

ISSN: 1734-7009 **eISSN:** 2084-0535

DOI: 10.2478/phr-2022-0001

Pages: 24, figures: 3, tables: 0

page www of the periodical: www.phr.net.pl

Publisher
Polish Hyperbaric Medicine and Technology Society

Original article

Submission date: 13.03.2021 r.
Acceptance for print: 14.05.2021 r.

INTRODUCTION

The introduction will briefly outline the definitions that will be needed later in the article.

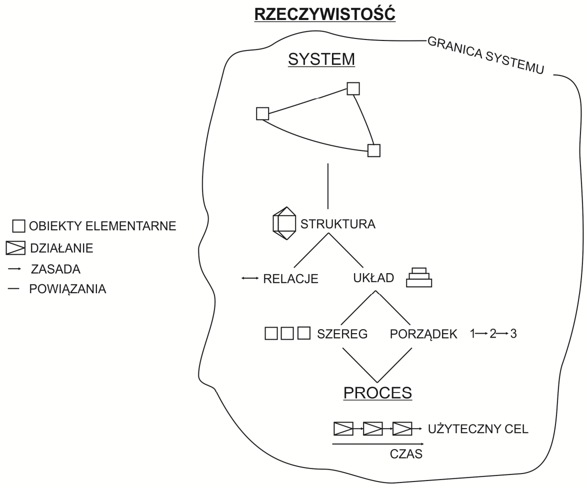

Fig.1 Pictogram model of the system and the process taking place in it.

PROCESS

A process is a series of activities taking place over time to achieve a specific objective. The conditions affecting the *process* are the internal and external context[8] – fig.1.

The process can only take place in a system that can ensure its *homeostasis* allowing it to be carried out with an approved level of risk of failure.

SYSTEM

The distinguished[10] *system* is a reasonably minimal[11] set of elements together with synergic[12] relations between them, guaranteeing the possibility of running the processes defined in it – fig. 1.

Unlike natural systems, for which the purpose[13] of the processes[14], taking place within them is not always known, a man-made system should have a rational basis, at least in its intention.

The elements of the system together with the relations form the structure of the system, in which we can distinguish: order, system, series, relations, etc.

PROCESS APPROACH

All rational human activity can be presented as a process, which can only take place in the supporting system environment, which is a set of synergetically related elements that make up the system structure, distinguished from the surrounding reality and defined by the internal context.

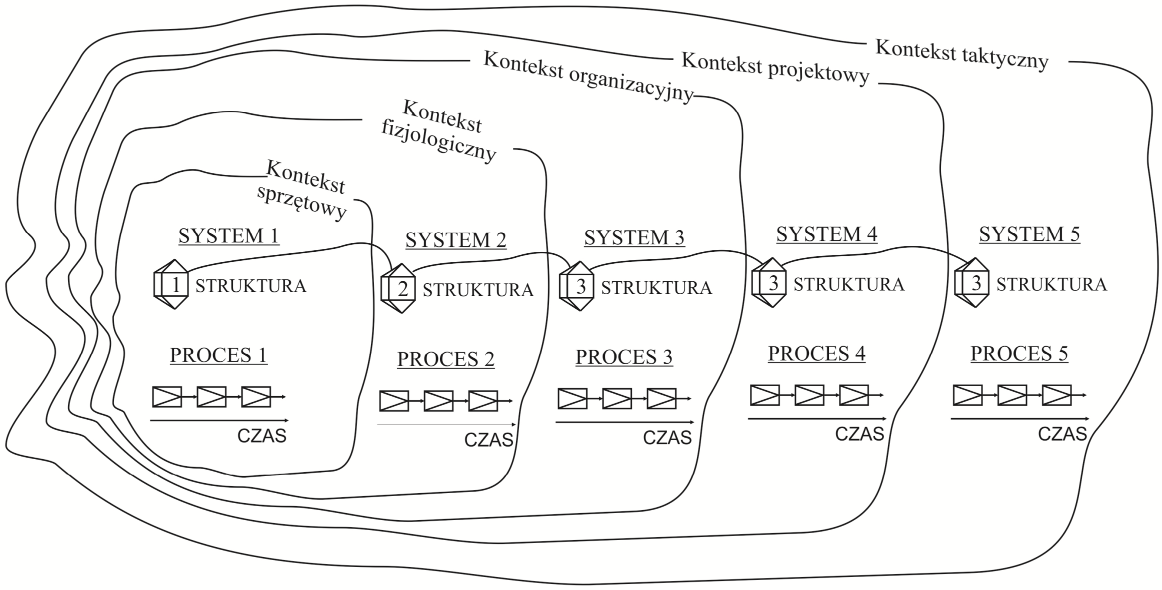

Fig. 2 Pictogram model of system boundary shifting depending on the chosen context:
SYSTEM STRUCTURE: 1-elements forming the technical armament such as: essential and emergency breathing devices, devices for descending the diver, providing thermal protection, hyperbaric treatment, etc.; 2-norms of oxygen toxicity, homeostasis ranges, decompression regimes, etc.; 3-organisational rules, legal norms, etc.; 4-research methods, project management rules, Bioethics Commission permits, etc.; 5-principles of warfare, in this case mine warfare.
MAIN PROCESSES: 1-technical execution of diving; 2-safe and efficient conduct of exposure and decompression; 3-safe and efficient conduct of underwater works; 4-efficient and timely achievement of the unique goal of technology development; 5-efficient fine-tuning of tactical requirements.

The external context consists of elements connected with system elements, but lying beyond the system boundaries – Fig. 1. Depending on the needs of the conducted analyses, system boundaries may be shifted – Fig. 2. Such modelling of human activity is called a process approach.

PERCEPTION

The understanding of reality is realised through the construction of simplified models, as the surrounding reality is too complicated in relation to the possibilities of our perception[15].

MODEL

A model is a maximally simplified version of a real system capable of supporting the process of interest with the required precision and accuracy.

Theoretical models are often built on the basis of structural isomorphism[16] of known systems, homology[17] to the known process and analogy[18] to known processes occurring in similar systems.

At the initial stage of building models, cybernetic models[19] are often used, reflecting the basic structure of the system supporting analogous to the original process of information exchange inside and outside the system.

In the current market conditions, for every type of human activity, economic modelling is extremely important[20]. In respect to the implementation of projects, it often takes the form of a feasibility study.

VALIDATION

Validation is the process of confirming in a documented and compliant manner that a model of a system or a process established on the basis of theoretical considerations is of sufficient reliability for the intended purposes. If validation is conducted based on statistical models[21], it should first be evaluated from an economic point of view, given its often considerable cost[22].

IMPLEMENTATION

Successful completion of the validation process enables model implementation[23].

MONITORING

In most cases, the analytical approach is unable to predict all interactions between system elements. Therefore, the system structure, built on the basis of such an analysis, must be checked in terms of meeting the requirements for the ability to unquestionably sustain the processes to which the system was dedicated. A system-wide check of the efficiency of the system is called a holistic approach. Even the adoption of a previously proven technology[24] must be validated in its adaptation to the use in a specific system environment, especially if it concerns technology with a high risk load. In addition, such technologies should be compulsorily, at least periodically checked[25] and accidents arising from their use investigated in detail[26].

DIVING TECHNOLOGY

Traditionally, when testing diving systems, the methodology used in Poland was based on assessing the risk[27] of decompression sickness (DCS) using statistical inference methods. The classical approach is based on statistical inference on the basis of performed experiments based on binominal distribution[28]. A similar approach may be applied to assess the risk of oxygen toxicity, especially the central form of oxygen toxicity (CNSyn).

A validation experiment is planned on the basis of the available knowledge of the system, which in this case is an ergonomic machine-human system[29]. The same experimental hyperbaric exposure is then multiplied with the required reproducibility and repeatability[30] and the system responses are collected in a dichotomous form[31]. The compiled results are used to determine the risk of DCS or CNSyn, expressed in terms of the probability of this risk materialising in the future, according to statistical inference based on an assumed statistical distribution. Such inference requires considerable effort to carry out experimental dives[32]. To confirm from the binomial distribution that the risk of DCS [6] is less than 1% at the 95% confidence level, a minimum of 299 experimental dives must be completed without a single case of DCS occurring. If one case of DCS occurs during the cycle the study can be continued until 555 experimental dives have been completed without the occurrence of any more cases of DCS to confirm the risk of decompression sickness at the same level [7,8].

Under domestic conditions, the application of the inference method based on binomial distribution is not practicable. Therefore, to date, it has only been conducted as a screening study using sequential analysis [9]. A similar approach was proposed by the Naval Medical Research Institute of the US Navy [10]. The procedure ensures the rejection of decompression schedules that generate a risk of DCS symptoms greater than 10% after a maximum of 40 experimental dives[33] with a probability of approximately 90% [4].

In Poland, this approach has been used for the cumulative decompression and ventilation model, as it is unrealistic under domestic conditions to use this procedure to validate every decompression schedule provided by the diving technology[34].

At present, due to the filling of the knowledge gap related to the possession of national deterministic and statistical models of DCS risk and CNSyn, validation based on binomial distribution has become possible with the application of models to the entire technology. However, this approach may lead to reduced effectiveness of the technology so developed in some areas of its use[35] [1].

PROJECT

A project is a temporary activity, typically taking place in a changing and uncertain environment, with a defined start date, scope, budget, and unique objective which, if achieved, can bring the project to a halt, and a defined end date which applies even if the project objective is not achieved. On the basis of the defined unique objective, the project has a specified proposal of the process for its achievement[36], with a minimal and optimum system structure [37] capable of ensuring stable and effective implementation of this process, taking into account both the impact on the environment and the impact of the environment on the system, and the process taking place in it.

CONTEXT

The knowledge acquisition and process approach will not be characterised in detail here, as they has been previously described [1]. The equipment, physiological, organisational, research and design and tactical contexts[38] have also been outlined in general terms earlier against the background of the main purpose of the diving process [2]. However, the tactical context will be further developed here.

In the description of the tactical context it was pointed out that, in military diving, the dominant role is played by the use of diving gear and equipment as structural elements of the system ensuring the implementation of processes resulting from the adoption of specific tactics.

In the definition of the project tasks, diving is an element of the system serving the processes of ensuring the protection of own forces and public safety, which can be divided into three subsystems: MCM[39], EOD[40] and IED[41]. The aforementioned protection of own forces and public safety consists of the context of mine warfare, where diving is a way of moving forces, similarly to the independent movement of subunits on land.

The tactical context of mine warfare provided the system context for the project. It was the starting point for specifying the main objective of the process carried out in the system environment, which is the diving technology in the context of mine warfare assumptions.

The systemic tactical context of the project will be characterised from the point of view of the normative documents of the NATO Standardisation Organisation.

NAVAL MINES

Naval mines are one of the main types of armament used at sea. They are cheap and simple devices, easy to produce and deploy, not excluding the current trend towards so-called ‘smart’ mines. Coastal waters require all navies to be capable of locating and destroying naval mines in order to minimise the risk of damage to ships and vessels operating on approaches to various maritime infrastructures, and to ensure the safety of shipping [10].

A fundamental element of the context to the dive operations system, in addition to physiological and equipment barriers, are the general principles of MCM mine warfare[42]. The diving operations scenarios are the basic element of the structure of the subsystem for the use of divers in the MCM mine warfare system. The operational scenarios provide the basic requirements for the selected underwater technology. An additional subsystem may be the use of MCM divers in special operations. Thus, operational scenarios have an impact on underwater work execution technology, which has a fundamental influence on the development of an adequate decompression system[43].

Currently, a trend is observed towards a significant reduction in the use of divers in MCM mine warfare and a marked increase in their use in special operations, whether military or police[44]. Often mine operations are conducted covertly, without the use of electronic support[45]. Covert action in special operations is understandable. With IED operations dedicated against smart mines, this requirement is also reasonable. Any system of guided or autonomous charges equipped with any internal[46] or external[47] intelligence system can be considered a smart mine. For example, an autonomous, self-propelled charge[48], a torpedo, a rocket-torpedo, a cruise munition, etc., may also be considered a smart mine at present. In contrast to covert operations and IEDs, typical EOD diving operations, dedicated to UXO elimination[49], can be supported by electronic equipment.

NATO DOCUMENTS

Recently, many NATO standardisation documents have been withdrawn. This is due to a change in the approach to these documents, which cease to serve as a common base of baseline knowledge and become only a form of minimum agreements applicable in case of joint operations. Thus, a significant part of the didactic value of these documents has been lost, while at the same time increasing the possibility to conduct faster implementations without the need to conduct state-of-the-art arrangements.

A transitional period of document reordering is currently underway, hence old documents developed as knowledge bases occasionally still exist. These include the Guidelines for the Maritime Safety of Ships [11]. This relatively new document upholds in effect, among other things, a rather old document specifying recommendations for mine warfare ships MCM [10].

In Annex A: General problems of MCM operations do ANEP-16 the main definitions are listed and the types of MCM operations are described. According to ANEP-16 the following main types of active MCM operations are distinguished:

- mechanical: minesweeping with devices designed to cut the mooring lines of mines,
- activation: inducing a mine trigger by simulating a target signature in the form of a magnetic, acoustic, pressure, electric field or a combination thereof,
- MH[50] operations: detection of individual mines by means of tracking devices and their subsequent removal or recovery for research purposes by vehicles or divers operating from the exploration vessel,
- CDO[51]: location and clearance of mines by divers limited to relatively shallow waters.

According to ANEP-16 three phases can be distinguished in MCM operations as general operational scenarios:

- reconnaissance: preliminary survey of an area or route to determine the presence or absence of mines. The most effective means of execution for these operations are MH tactics,
- demining: using MH tactics or minesweeping, which are designed to remove or reduce mines from a defined area to a defined mine clearance level[52],
- maintenance/destruction[53]: they are an extension to demining operations when it is necessary[54] to maintain a low risk to shipping.

The scenarios described in ANEP-16 take into account only maritime mine countermeasures MCM omitting military and police special operations[55], rescue[56] and destruction operations[57], etc. To these we may add active mine action security operations in maritime and inland waters[58]. Elements of these scenarios were described earlier in the context analysis in the subsection: Tactical context [2].

A general overview of how CDO diving operations are conducted in NATO in the maritime mine countermeasures system MCM is described in Chapter 7 Clearance diving operations in the document MTP-24 Naval mine countermeasures – tactics and execution [12]. MTP-24 was introduced by the standardisation provision STANAG 1132 [13]. Chapter 7 MTP-24 outlines the general principles for the use of existing equipment and methods employed strictly in conjunction with Allied Guide to Diving Operations[59] ADivP-01 [14].

Under MTP-24 scenarios of mine countermeasures MCM implemented as clearance diving operations CDO are operations carried out autonomously by CDTs[60] with authorisation to locate, identify and remove mines and underwater munitions. MTP-24 does not restrict the operations carried out by CDTs to shallow waters VSW[61], as in ANEP-16.

According to MTP — 24, the objectives of mine counteraction diving operations CDO are: to locate, identify and eliminate mines[62].

The ability of CDTs to achieve these objectives are affected by the conditions on the surface[63] and under water[64]. The capabilities to conduct CDOs is also impacted by the equipment and breathing mixes used. The conditions for conducting CDOs are described in ADivP-01 [14]:

- Section One. Chapter 1: General Considerations on the Use of Divers.
- Section Two. Chapter 11: Diving Breathing Gases and Interoperability of Gas Supplies.

Pursuant to MTP-24, CDOs can be conducted as part of MCM also at depths greater than the near-shore operations (VSW), as suggested in ANEP-16. Of course, it should be understood that the limitations detailed in ANEP-16 have been introduced from the operational point of view of a vessel for which navigating in close proximity to the shore is hazardous. According to MTP-24, in the planning process for the use of CDTs to carry out CDOs the use of experts in MCM should be considered in concord with MTP-6 Volume II: Naval mine countermeasures operations planning and evaluation, Chapter 11: Mine countermeasures planning and evaluation methods using an MCM expert. When planning MCM using CDOs while taking into account this recommendation, the qualities of technical mission accomplishment are combined with the involvement of expert knowledge. This is particularly useful when diagnosing[65] unidentified mine-like objects UMO[66]. Hence, operations conducted by means of CDOs continue to play an important role in mine warfare tactics.

The introduction to ADivP-01 clarifies the basic types of diving missions carried out in NATO. Within MCM diver support operations counteracting naval mines, whereas in the field of EOD/IED divers are used to identify potential UXO/UMO, to remove or neutralise explosives IED, or for reconnaissance during customs clearance. Within the scope of disposal or neutralisation of explosives, divers are used to perform passages[67], remove obstacles, demolitions, etc. In the field of rescue operations, divers extract or free own equipment used during MCM, or can also perform destruction of technical objects, thus preventing their takeover by the enemy.

In Chapter 5: Self-contained mixed gas diving deeper than 54 metres it was stated that the specific objectives of deep diving are tasks undertaken as part of MCM, such as: detection, reconnaissance, clearance and neutralisation of mines and UMO, while maintaining the acoustic and magnetic field limits agreed with the NATO limits of acoustic and magnetic fields emitted by the equipment of a diver or a CDT. At present, the diver's gear is one of the elements of equipment used in MCM with the lowest signatures of the electric, magnetic, acoustic or pressure fields. Hence it is still an extremely effective technology, especially in the identification of mines and UMO suspected to be weapons equipped[68] with sensors and actuators[69], also with elements of artificial intelligence. The use of diving technologies is limited to the area[70], depth and effective diver activity. The capabilities related to depths achieved by particular NATO countries are summarised in Chapter 7: National diving capabilities ADivP-01.1 [15].

Currently, the destruction of detected UXO is most often carried out by conducting diving counter-mine operations CDO. AODP-10 Explosive ordnance disposal (EOD) principles and minimum standards of proficiency specifies the scope of authorisations and skills in this area [16]. AODP-10 was introduced by a standardisation provision STANAG 2143: Explosive ordinance disposal (EOD) principles and minimum standards of proficiency [17]. Generally, according to AEODP-10, reconnaissance personnel EOR[71] qualified to perform tasks with the use of explosives EO[72] underwater in the course of NATO missions must meet the minimum standards of proficiency specified in Annex E: Minimum standards of proficiency for underwater EOD. In addition, EOC[73] personnel are authorised to deploy explosive devices EO under the supervision of a CMD[74] diver.

AEODP-10 emphasises the key role of divers in the acquisition and identification of enemy explosive devices. Procedures in this regard are specified in the AEODP-14 NATO EOD publications set (NEPS) – Identification and disposal of surface, air, and underwater munitions [18]. AEODP-14 was introduced in order to meet the requirements of the STANAG 2369 EOD publications set (NEPS) – Identification and disposal of surface, air, and underwater munitions [19] by providing information on the identification and disposal of surface, air and underwater munitions. It is a publication derived from the US Explosive Ordnance Disposal Publication System AEODPS consisting of information that have been validated and found to be available for NATO.

In mine warfare MCM it is essential that any unknown explosive charge (EO) of the enemy is secured, possibly in a non-destructive manner for examination by specialists. Before the reconnaissance phase and further exploration takes place, the initial task of reconnaissance carried out by divers EOD is to decide whether the object is a UMO/AXO[75]. This function is particularly important in the case of IEDs, as the information obtained can be used in C-IED[76] procedures [20,21].

In the marine environment, specialised CDTs are tasked with the investigation and exploitation of newly discovered AXO, with the use of specialised tools, equipment, tactics, techniques and procedures (TTP)[77]. If the movement of AXO or a tactical situation does not allow for immediate exploration[78], extensive documentation, including photographs and details of all markings must be completed prior to on-site destruction for future AXO identification.

The AJP-3.15: Allied joint doctrine for countering improvised explosive devices specifies the tasks of CDTs as related to countering improvised explosive devices C-IED concentrated on: search, detection, location, identification, and neutralisation – IEDD[79], investigation activities and the collection of material for analysis after and underwater explosion [20,21]. So, in relation to C-IED, EOD divers form demining teams CDT, which are operational factors supporting the protection of troops (FP)[80] by searching for and elimination of IEDDs in the marine environment.

Operations in contaminated or polluted waters, or works on chemical, biological, radioactive or nuclear explosives CRBN EO[81] must be carried out by a specialised diving team CDT, in accordance with the ADivP-01 [14,22].

PHYSICAL FIELDS

Mines can trigger their destructive action through contact or through the influence of fields, most commonly magnetic, electric, acoustic, pressure or seismic fields[82], in any combination of these.

Mines can be moored on long or short anchor lines, lie on the bottom or be buried in it. Naval mines may also have the ability to move, track a target[83], camouflage themselves[84], combat countermine guided charges[85] $EMDV$[86] or counteract divers [10].

Physical fields are an important context for the selection of technologies to be used in MCM, as mines can be equipped with actuators to counteract their detection, removal[87] or overpowering on the basis of processes of diagnosis[88] physical fields and generating[89] their changes on the basis of physical fields measurements with the use of appropriate sensors.

One of the most commonly diagnosed physical fields is the acoustic field, generated both by objects in close proximity to mines and from sonar beam sweeps. Although the theoretically effective, guaranteed range of active hydroacoustic de- tection may reach[90] $800\ m$, this is an extremely useful method. Most often, smart mine detectors will be geared towards passive detection, which has a much smaller radius and is subject to strong interference. $NATO$ provisions on acoustic signature limits[91] and their measurements are summarised in the standard $AMP-15$ [22], which was introduced by standardisation agreement $STANAG$ 1418 [23]. Chapter 6 *Measuring and reporting acoustic characteristics of divers and their equipment*. $AMP-15$ also contains measurement requirements for determining the acoustic signatures of diving equipment, and their limits are specified in a classified supplement to $AMP-15$.

Another important physical field is the magnetic field[92], for which requirements are included in $AEODP-07$ *Explosive ordnance disposal equipment requirements and equipment*[24]. In Annex A to $AEODP-07$ it has been clarified that divers are used to detect underwater UXO/AXO, and Annex B in point $B6$ defines the scope, whereas point $B7$ the manner of testing the equipment of divers cleared for this task. According to these provisions, diving apparatus and other equipment intended for underwater EOD should be subjected to the typical MCM equipment static magnetic tests[93], as specified in point *B*5, and may be subjected to dynamic tests in an underwater environment.

Research conducted on perimetric protection[94] using pressure field analysis for diver detection, by measuring fin-induced pressure changes and shock-induced vibrations has been previously described [25]. However, these diver detection routes have not been developed into *NATO* standardisation documents.

COUNTERACTING DIVERS

Anti-diving systems are based on the detection of physical fields produced by divers, but also on other measurements, carried out by video cameras or laser sensors.

Sonar technology is used to find and track targets, including those with such poor target strength[95] as divers. Commercial solutions already exist, such as *Cerberus*[96] manufactured by *ATLAS Elektronik UK*. This is an intelligent sonar capable of detecting the air-filled chest of a diver and allow the operator to distinguish the echo coming from a human, or an animal such as a seal or dolphin. Moreover, it can distinguish a human from a school of fish, cavitation bubbles induced by the propeller of a surface or underwater platform, etc. Similar target locating and tracking systems can be used as part of external intelligence[97] of a mine or a minefield.

In Poland *Ośrodek Badawczo-Rozwojowy Centrum Techniki Morskiej S.A.* [*Research and Development Centre of the Maritime Technology Centre S.A.*] has its own systems with similar properties, tested under the project of the *National Centre for Research and Development NCBiR* No. O R 0000 98 1 *Detection and counteracting of underwater attack*.

The use of magnetic anomaly sensors, can be an effective method for finding divers over relatively short distances. The radius of effective detection of magnetic field changes generally does not exceed 10 m. However, it is a relatively effective method in shallow water regions. Near infrastructure, this method requires compensation for existing magnetic field anomalies.

Sonar and magnetic surveying techniques are not very effective on waterways due to interference from passing surface vessels and, in general, clutter from magnetic elements.

Classic detection methods in perimeter protection[98] against divers have been the use of: vision methods[99], animals, barrier nets equipped with accelerometers, sonar obstacles, etc. Currently, attempts are being made to use green laser systems or pressure sensors. Measures used to fight divers include small explosive charges, firing from anti-aircraft guns[100] or coupled guns, air guns, sonar pulses, animals, abrasive weapons[101] etc.Technical means of passive detection of combat divers[102] are often located on the bottom and their effectiveness decreases drastically with distance. Staying close to the surface minimises the risk of detection by these technical means.

Also for active sonar systems used to detect divers, surface detection is less effective[103] especially in cases of a larger target on the sweeping course, such as a surface vessel, drifting debris, fauna, a layer of air suspended solids formed during wave action, etc.

As already mentioned, for technical safeguards, specialised sonar systems, designed specifically for diver detection, are most often employed[104]. A diver is an object with relatively low target strength and small dimensions, hence these devices are characterised by a limited effective range, which depending on hydrological conditions ranges between 300-800 m [26]. When approaching an unrecognised shore, the 800 m operational radius is assumed to be the smallest due to the possibility of the presence of technical shore infrastructure equipped with protective/reconnaissance devices[105].

The disadvantage of the diver remaining at shallow depths in clear water is that it may increase detection by surface observers. However, due to water reflections, they would need to be relatively high and at an angle ensuring that the reflections would not blind them[106]. Promising results are expected with the use of green lasers to detect shallow-water objects. These are already being used in technical structures such as breakwaters, jetties and piers that can make it easier for divers to navigate and hide.

In turbid water, in the absence of respiratory emissions, a diver is a difficult target to detect, provided he does not cause turbulence on the surface due to intensive finning.

MISSIONS

In the past, reconnaissance of mine-like *UMO* objects was only carried out by conducting dives. Reconnaissance by technical means has now become possible, although visual inspection by divers still performs an important role. It is also the only method to acquire *UXO/AXO* for reconnaissance purposes [27]. Reconnaissance is carried out to retrieve *UXO* by picking it up with an attached rope or net with or without prior immobilisation[107].

In-situ clearance is carried out to remove *UXO* suspected of being set in an unrecoverable position on a critical structure, for example the side of a ship. Explosive deflagration[108] may prove to be a useful method. *UXO* placed on critical infrastructure should be neutralised[109] or removed using the quickest method possible[110].

The in-situ clearance of *AXO* suspected of being set as non-recoverable or threatening to explode during displacement is carried out almost exclusively by means of diving missions.

In-situ reconnaissance and destruction of *UXO* carried out by divers of the *CDT* is practically performed using spot diving technology with the ability to move within a limited radius.

Another basic combat mission scenario for *CDT* divers is the execution of demining, usually accomplished with explosive charges. Deflagration is not used in this case. This scenario is usually performed in a maximally covert manner. Where full covertness is not required *CDTs* may be supported by an underwater vehicle system, as shown in the example of *VSW* diving operations with AUV support. This type of operation to prepare a landing site for invading forces by blowing up defence infrastructure is not considered in national doctrine, as naval landing operations were abandoned by the Polish Army in 1993.

COMMUNICATION

Spot dives are usually conducted on a lowering line or on a tether[111]. When visibility is good, dives to relatively shallow depths can be conducted without cable system protection. Whenever possible, MCM operations should be conducted with communication protection. Training dives can be secured with simplex safety communication systems, command post→diver, through loudspeaker systems carrying the message to the diver through the water.

School dives should be secured by wired communication systems. Deep dives, even in good visibility, should be secured with ropes due to the possibility of deep currents. In areas of low and medium visibility diving without safety lines is rather impossible due to limited use of electronic navigation and communication systems. If the lifeline also serves as a wired communication system[112], it is questionable whether a diver equipped with such a communication system should approach a mine. Secure telephones are used to suppress electromagnetic fields from the communication system[113]. The microphone transducer converts sound pressure into electrical current, which is then converted back into sound by the receiver transducer. Most telephones powered by sound use a dynamic microphone without signal amplification.

DIVE PLANNING

Diving technology should take into account the possibility of compensating for situations that may occur during the execution of diving operations both in training and during the execution of tasks, in peace and war time.

Mine countermeasures are usually performed in offshore as well as near shore conditions, hence a diving system dedicated to *MCM* operations does not usually need to take into account decompression in reduced pressure conditions occurring in the conditions of elevation of a body of water, as in high mountain lakes. Similarly, these operations are not usually carried out in deep pits nor is decompression carried out to the elevated pressures found in air traps, as can happen in flooded mines or caves. The implication of this is that diving technology does not need to take such scenarios into account. In offshore conditions, the effect of wave action on the diver is present, hence decompression systems for offshore diving technologies are required to accommodate the possibility of completing the decompression at a greater depth than is assumed in typical decompression schedules.

Due to the resignation of the Polish Navy from offensive landing operations, *MCM* diving technologies do not necessarily include the divers' ability to independently cover significant distances underwater. However, *MCM* operations accompanying the activities of special sections *SRT* during both military and police operations may require the undertaking of such operations.

In many cases, stealth plays an important role. Not just tactical stealth when operating in close proximity to the enemy, but also in terms of protecting the diver against defensive systems of smart mines[115] or mines set to be non-removable[116]. Tactical stealth requires the use of self-contained diving devices. In a peacetime environment, it is more important to maintain stealth against smart mines, so it is acceptable to use wired systems which can provide a longer duration of protective action. The intensity of underwater work may also be increased by considering the possibility of successive dives[117]. The possibility of conducting successive dives is closely related to the problem of maintaining fitness divers to undergo decompression and performing diving.

The organisation of military operations often involves the use of air transport, therefore the decompression system should define the possibilities and rules for flights, especially after diving.

Air apparatuses are seldom used in MCM diving. The use of special-purpose breathing apparatus, especially with a semi-closed circuit breathing mix, is connected with the search for its optimal composition. One of the parameters determining the efficiency of diving operations is the ratio of the time which can be allocated to work vs the decompression time. Minimising this ratio involves considering a compromise between the decompression process and oxygen toxicity. Diving technology should be able to balance these two risks, while also taking into account the processes of accelerated decompression in depth or surface decompression. The application of changes of breathing medium during the diving process should also consider the risk of losing one of them and hence the equivalent use of another available breathing mix. Additionally, emergency situations related to aborted dives, prolonged exposure, descents or shortened planned stay should be based on pre-planned emergency scenarios.

SUMMARY

Military tactical thought is moving towards eliminating the soldier from the battlefield. For example, this is now evident in military aviation, where the role of unmanned aerial vehicles $UCAV$[118] has considerably increased. In particular, battlefield reconnaissance and precision attacks are dominated by the use of UCAVs. The scale of implementation of unmanned technologies in aviation seems to eliminate even the need for satellite reconnaissance[119].

Similar trends are observed in land operations, where a significant increase in the role of unmanned robots is observed in the areas of reconnaissance, transport, demining, combat operations, etc.

Combat operations require the seizure of territory, its control and maintenance. As yet, this does not seem to be feasible, if only because of the need to introduce police operations in the occupied area to maintain public order. But reconnaissance and combat systems can already be networked centrally into air-sea-land systems.

Typical maritime operations are also becoming progressively automated. We are witnessing an increasing role for reconnaissance systems, both from the air

from the water and from under the water. However, for the time being, operations in support of combat operations from the water or from under the water most often require the use of manpower, even in peacetime conditions. This is due to the economics of military operations. Combat systems for mine neutralisation are relatively expensive. Forces are equipped with self-propelled explosive devices $EMDV$[120], such as: $SeaFox$, $ArcherFish$ czy $Głuptak$, but in order to economise remote operations based on $ROUVs$[121], such as: $SeaFox/Cobra$ or $Ukwiał/Toczek$ have been introduced.

Outside of military exercises, however, all *EOD* operations are performer by *CDTs*, due to cost considerations. The use of *EMDV* self-propelled explosive charges, or ROUV systems dedicated to mine countermeasures *MCM*, usually requires the close assistance of a mine warfare vessel *MCMV*[122]. These ships are built to withstand nearby explosions. Operations by *CDTs* can be conducted at a considerable distance from the assisting vessel, hence it does not need to be of the *MCMV* class. The trade-off is that divers operating from a small RIB-class boat must be equipped with diving apparatus and tools[123] to ensure they can work fully autonomously away from surface or shore support.

Sometimes mine action is carried out covertly, without the use of electronic support[124]. Covert operations are an absolute requirement for special operations. In *MCM* and *IOD* operations, dedicated to counter intelligent mines, this requirement is also reasonable. When conducting EOD operations, with the exception of *UXO* clearance, it is possible to support diving operations with electronic equipment and devices, hence there is ample room for the use of unmanned systems. However, precision mine clearance operations both at sea and on land are still conducted using humans.

The majority of hazardous *MCM* activities carried out in peacetime are organised through the use of *CDT* groups, although it would seem that in these operations direct human exposure should be eliminated as a priority. This is arguably due less to a technological gap than to economic conditions. For example, even if it is possible to directly eliminate a sea mine by using unmanned systems such as *SeaFox* or *Głuptak*, as this does not threaten any infrastructure or environment, their cost is considerable. The use of *CDTs* using conventional explosives to trigger an explosion or specially shaped and applied charges to deflagrate a *UXO* charge are much more effective methods from an economic point of view. This is shown by the analysis of recent *UXO* activities in Polish waters.

CDTs are not only indispensable in the acquisition of, for example, *IEDs*[125], but also in situations where it is unacceptable to clear or trigger an explosion. This was the case with the deflagration[126] of the British *Tallboy* bomb, weighing 5340 kg from the time of World War II, performed in 2020 on the Szczecin-Świnoujście waterway by 13 *dTr*. The detonation of the bomb posed a direct threat to a nearby ferry crossing, pipelines and coastal infrastructure.

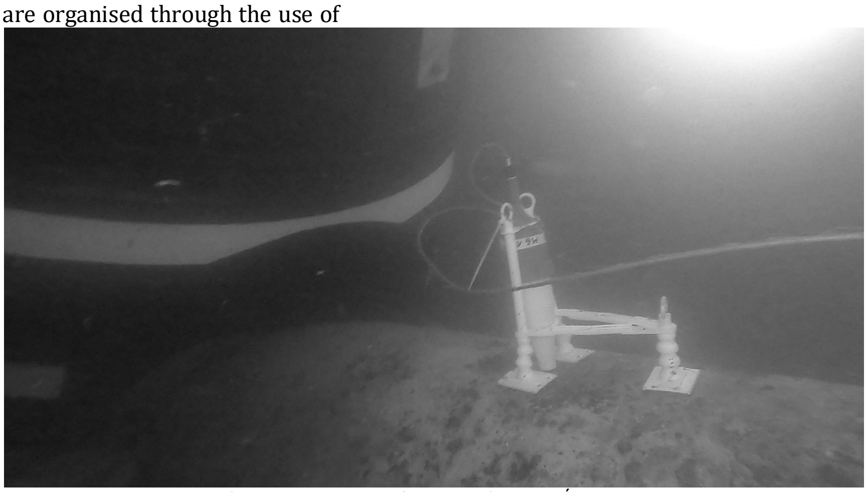

Fig. 3 One of the applied incendiary charges on the body of the *Tallboy* bomb. [Courtesy of 13 *dTr*, Świnoujście].

An attempt to remove the bomb was likely not only to cause damage to the aforementioned infrastructure, but also posed a risk to the *CDT* at work and the equipment used. Initiating the deflagration process, however, required precise positioning of the incendiary charge as far from the bomb's fuses as possible, a task best left to a *CDT* group – fig. 3.

CONCLUSIONS

The system tactical context constitutes the basis for specifying requirements as to the elements of the system structure and subsystems - thus allowing for conducting research into its properties, e.g.: reliability, vaporisation, redundancy, etc.

When carrying out design tasks, it is essential to remember that diving represents only a small element of the system serving the realisation of processes within the larger MCM mine warfare system. In its essence, diving is merely a means of moving forces to perform tasks arising from *MCM* objectives.

The national tasks falling to the *CDT* groups had to focus on spot diving as the primary scenario arising from *MCM* needs. Other scenarios became less relevant after the maritime landing force was demobilised in 1993.

FINAL NOTES

The article is the result of the project No. DOB-BIO-12-03-001-2022 dated 2.01.2023 r. for the implementation and financing of the project carried out for national defence and security within the framework of the Competition No. 12/2022 NCBiR entitled "The impact of combat effort and air transport on the safety of combat divers during underwater combat operations" implemented in 2023-2025.

REFERENCES

1. Kłos R. 2019a. Designing of diving technologies – process approach. *Polish Hyperbaric Research.* 1, 2019a, Tom 66, DOI: 10.2478/phr-2019-0001, strony 7-24.
2. Kłos R. 2019b. Context analysis in the development of diving technologies. *Polish Hyperbaric Research.* 2, 2019b, Tom 67, DOI: 10.2478/phr-2019-0005, strony 7 – 58.
3. Kłos R. 2000. *Aparaty Nurkowe z regeneracją czynnika oddechowego.* Poznań : COOPgraf, 2000. ISBN 83-909187-2-2.
4. Kłos R. 2011. *Możliwości doboru dekompresji dla aparatu nurkowego typu CRABE - założenia do nurkowań standardowych i eksperymentalnych.* Gdynia : Polskie Towarzystwo Medycyny i Techniki Hiperbarycznej, 2011. ISBN 978-83-924989-4-0.
5. .Kłos R. 2016. *System trymiksowej dekompresji dla aparatu nurkowego typu CRABE.* Gdynia : Polskie Towarzystwo Medycyny i Techniki Hiperbarycznej, 2016. ISBN 978-83-938322-5-5.
6. (Klos R., Nishi R., Olszanski R., 2002)
7. Kłos R. 2007. *Zastosowanie metod statystycznych w technice nurkowej - Skrypt.* Gdynia : Polskie Towarzystwo Medycyny i Techniki Hiperbarycznej, 2007. ISBN 978-83-924989-26.
8. Wienke B.R., 2016
9. Wald A. 1947. *Sequential Analysis.* New York : Jon Willey & Sons, Inc., 1947.
10. Homer L.D. Weathersby P.K. 1985. Statistical aspects of the design and testing of decompression tables. *Undersea Biomedical Research.* 1985, Tom 12, 3, strony 239-249.
11. ANEP-16. APRIL 1989. *Mine Countermeasure Vessels SUPPLEMENT 2 to STANAG 4154 -General Criteria and Common Procedures for Seakeeping Performance Assess-ment mine counter measure vessels.* Edition 1. Brussels : NATO Standardization Office, APRIL 1989. CPT 2041.
12. STANAG 4154. 22 February 2018. *Common procedures for seakeeping in the ship design process.* Edition 4. Brussels : NATO Standardization Office, 22 February 2018. NSO/0241(2018)SDCG/4154.
13. MTP-24. May 2002. *Naval mine countermeasures - tactics and execution.* Brussels : NATO Standardization Agency, May 2002. Tom I. MTP-24(C) VOL I.
14. STANAG 1132. 26 September 2016. *Naval mine countermeasures - tactics and execution* . Brussels : The NATO Standardization Office, 26 September 2016. NSO(NAVAL)1177(2016)NMW/1132.
15. ADivP-01. September 2019. *Allied guide to diving operations.* Edition C Version 3 . Brussels : NATO Standardization Office, September 2019.
16. AEODP-10. February 2020. *Explosive ordnance disposal (EOD) principles and minimum standards of proficiency.* Edition C Version 1. Brussels : NATO Standardization Office, February 2020.
17. STANAG 2143. 7 FEBRUARY 2020. *Explosive ordnance disposal (EOD) principles and minimum standards of proficiency* . 7. Brussels : NATO Standardization Office, 7 FEBRUARY 2020.
18. AEODP-14. June 2016. *NATO EOD publications set (NEPS) – Identification and disposal of surface, air, and underwater munitions.* Edition A Version 1. Brussels : NATO Allied Explosive Ordnance Disposal Publication, June 2016.
19. STANAG 2369. June 2016. *EOD publications set (NEPS) – Identification and disposal of sur-face, air, and underwater munitions.* Edition 4. Brussels : The NATO Standardization Office, June 2016. NSO(ARMY)0845(2016)EOD/2369.
20. STANAG 2295. 8 February 2018. *Allied joint doctrine for countering improvised explosive devices (C-IED).* 4. Brussels : NATO Standardization Office, 8 February 2018. NSO(JOINT)0176(2018)C-IED/2295.
21. AJP-3.15. February 2018. *Allied joint doctrine for countering improvised explosive devices.* Edition C Version 1. Brussels : NATO Standardization Office, February 2018.
22. STANAG 1372. 28 July 2014. *Allied guide to diving operations.* 11. Brussels : The NATO Standardization Office, 28 July 2014. NSO(NAVAL)1054(2014)UD/1372.
23. AMP-15. May 2013. *Standards for naval mine warfare acoustic measurements.* Edition (A) Version (1) . Brussels : NATO Standardization Agency, May 2013.
24. STANAG 1418. 7 May 2013. *Standards for naval mine warfare acoustic measurements.* Brussels : NATO Standardization Office, 7 May 2013. NSA(NAVAL)0766(2013)NMW/1418.
25. AEODP-07. November 2015. *Explosive ordnance disposal equipment requirements and equi-pment.* Edition B Version 1. Brussels : NATO Allied explosive ordnance disposal publication, November 2015.
26. Korenbaum V., Kostiv A., Gorovoy S., Dorozhko V., Shiryaev A. 2020. Underwater Noi-ses of Open-Circuit Scuba Diver. *Archives of Acoustics.* 2020, Tom 45, 2, strony 349–357.
27. Pozański P. 2011. Współczesne zagrożenia elementów infrastruktury morskiej oraz systemy ich detekcji. *Polish Hyperbaric Research.* 2011, Tom 35, strony 7-34.
28. Greenlaw J. 2013. *Sea mines and naval mine countermeasures: are autonomous underwater vehicles the answer, and is the Royal Canadian Navy ready for the new paradigm?* . Toronto : Canadian Forces College, 2013. JCSP 39.
29. Ligęza K. 2013. *Leksykon działąń sił morskich.* Gdynia : Akademia Marynarki Wojennej, 2013. ISBN 978-83-60278-71-0.

dr hab. inż. Ryszard Kłos prof. AMW
Akademia Marynarki Wojennej im. Bohaterów Westerplatte
Zakład Technologii Prac Podwodnych
81 – 103 Gdynia 3
ul. Śmidowicza 69
r.klos@amw.dynia.pl

ORCID identifier No: 0000-0002-4050-3978

[1] it is a general tactic (see below for def.) which may not necessarily be perceptible to the public,
[2]the study of scientific research methods, their effectiveness and cognitive value,
[3] set of methods,
[4] a theory is a general concept based on knowledge and understanding of the relevant factors that shape a particular part of reality,
[5] a proven, effective and reproducible process for solving a problem and achieving a defined objective,
[6] **S**emi-**C**losed **R**ebreather,
[7] a pictogram is the representation of a concept by means of a picture,
[8] lying outside the system but influencing processes within it,
[9] the ability to maintain relatively constant internal parameters in the system,
[10] for example, by fixing the boundaries,
[11] if, for reasons of the method of system construction, it is necessary to use redundant elements, for example for safety reasons, this approach also falls within the term "reasonably minimal set of elements' as used here",
[12] joint impact is greater than the sum of separate actions,
[13] the purpose of basic research is to learn about these processes,
[14] for instance, it is not very clear what the process of natural nuclear decay is intended to achieve,
[15] the process of phenomenological cognition that takes place using only our sensory organs,
[16] the existence of different systems in the same type of system structure,
[17] existence of similar systems capable of supporting different processes,

[18] similarity of systems and their processes,
[19] a relatively isolated system, possibly of low complexity, working in a similar way to the original, to study information flow and control in modelled systems,
[20] an economic model is a mental construct comprising a set of assumptions adopted in economics to capture the most salient features and relationships in a given economic process,
[21] a probabilistic description to allow the risk of decisions to be evaluated when making inferences in a problematic situation,
[22] this means that it must not only be assessed in terms of financial viability, but also in terms of its social impact ,
[23] permanent introduction of the model into the knowledge system as a reliable tool for predicting the behaviour of processes in defined systems,
[24] process preparation and conduct method,
[25] for example, the Office of Technical Inspection in Poland is established to periodically check certain technical risks,
[26] for example, the State Commission for the Investigation of Air Accidents is established in Poland to investigate air accidents,
[27] the risk is understood here as the integral over time of the risk,
[28] as in the testing of new drugs or clinical procedures,
[29] rebreather – diver,
[30] usually one variable parameter is assumed for this multiplication, which is the person/experimental diver, extending the inference to the selected population of divers,
[31] presence or absence of DCS symptoms,
[32] which explains the long time it takes to confirm the marketability of medicines,
[33] after a minimum of 28 experimental dives,
[34] under domestic conditions, it is theoretically possible to conduct max. 150 experimental dives per year, but the cost of such procedure is approx. 1 million PLN net,
[35] for example, blocks of parameters are often used for certain ranges of stay times, which makes the technology thus developed more efficient, but the validation process is lengthened as it should be carried out for each block separately,
[36] resulting from tactics,
[37] through various analyses such as feasibility, competitiveness, risk and non-reliability studies,
[38] theory and practice of using resources to achieve a desired goal,
[39] **M**ine **C**ounter**m**easure,
[40] **E**xplosive **O**rdnance **D**isposal,
[41] **I**mprovised **E**xplosive Device **D**isposal,
[42] all such references as: Mine Warfare, Naval Mine Countermeasures or Naval Mine Warfare refer to Mine Countermeasures MCM and mean the same here,
[43] the decompression system will only be part of the operational scenario process,
[44] in asymmetric operations by regular armies and police against a poorly organised opponent,
[45] wireless communications, electronic navigation systems, electronically operated or controlled instruments, etc.,
[46] e.g. an autonomous system based on artificial intelligence,
[47] e.g. systems for remote control of a single mine or minefield using distributed intelligence (swarm intelligence), meaning cooperation between multiple robots without a predefined plan and without a single command body,
[48] also used for mine destruction,
[49] **U**ne**x**ploded **O**rdnance,
[50] **M**ine **H**unting,
[51] **C**learance **D**iving **O**perations
[52] most often expressed as the expected value of the probability of a ship hitting a mine, or the number of ships hitting mines remaining after the demining process [29].
[53] a process of progressive reduction of mine strength or effectiveness through continuous surveillance,
[54] due to mine replenishment or delayed arming mechanism,
[55] usually involving underwater reconnaissance, either as a typical underwater reconnaissance or merely as an element of a reconnaissance mission in the form of an underwater transport prior to reconnaissance, assault, diversion, barrier setting works,
[56] most frequently, the rescue of technology used in MCM,
[57] most frequently, the execution of penetrations and destructions to prevent the acquisition of military technology by the enemy,
[58] for example, surveillance of the activities of potential adversaries in mine warfare,
[59] ADivP – 01 was introduced by standardisation provision STANAG 1372 Allied Guide to Diving Operations [22],
[60] **C**learance **D**iving **T**eam,
[61] **V**ery **S**halow **W**ater,
[62] missing here is perhaps the most important task actually performed only by CDTs, related to the identification, investigation and analysis of acquired unidentified UXO or IOD,
[63] like sea state, weather, type of support, etc.,
[64] like water temperature, current, depth, type of bottom, mode of transport,
[65] diagnosis, understood here as the assessment of the condition based on examinationn and analysis following an underwater reconnaissance, underwater investigation, capture of an unidentified mine-like object (UMO) and analysis of the performance of the acquired whole or residual UMO,
[66] **U**nidentified **M**ine-like **O**bject,
[67] in both planned and ad hoc operations,
[68] understood as any means of warfare capable of inflicting losses on an opponent,
[69] Actuators are devices which, on the basis of the measurement made by the co-operating measuring system, cause the activation of the actuating element, for example triggering the heating, lighting, sounding the warning signal, etc.,
[70] area restrictions may concern certain parameters of a water body, such as its contamination,
[71] **E**xplosive **O**rdnance **R**econnaissance,
[72] **E**xplosive **O**rdnance,
[73] **E**xplosive **O**rdnance **C**learance,
[74] **C**onventional **M**unition **D**isposal,
[75] **A**bandoned E**x**plosive **O**rdnance,
[76] **C**ountering **I**mprovised **E**xplosive **D**evices,
[77] **T**actics, **T**echniques and **P**rocedures,
[78] understood as the study of unknown objects,
[79] **I**mprovised **E**xplosive **D**evice **D**isposal,
[80] **F**orce **P**rotection,
[81] **C**hemical, **B**iological, **R**adiological and **N**uclear **E**xplosive **O**rdnance **D**isposal,
[82] here concerning mechanical vibrations created in the bottom layer and in the water by impacts or mechanical movements, e.g. from thrusters, diving fin movements, etc.,
[83] circulating torpedoes similar to shore-based munitions,
[84] e.g. burying,
[85] e.g. German SeaFox, American Archerfish or Polish Głuptak,
[86] **E**xpendable **M**ine **D**isposal **V**ehicle,
[87] safeguards in the event of non-removability,
[88] a process aimed at determining the current state and making a diagnosis on this basis,
[89] a process to determine the presumed cause of a change over time,
[90] the effective range of hydroacoustic detection strongly depends on the season of the year,
[91] the characteristic sound signal of a specific acoustic wave structure emitted by a technical object, from which its identification can be made,
[92] also electrically induced,
[93] magnetic, electrical and stray current signature tests,

[94] protection against intrusion into the protected site,
[95] target force is the ratio usually expressed in decibels $[\mathrm{dB@1\ m}]$, it is a quotient of wave intensity $[\mathrm{W \cdot m^{-2}}]$ reflected from the target towards the receiver at a distance of $1\ \mathrm{m}$ from its centre and the intensity of a plane acoustic wave $[\mathrm{W \cdot m^{-2}}]$ incident on the target from the direction of the receiver,
[96] https://en.wikipedia.org/wiki/Cerberus_(sonar),
[97] cooperative systems that remain located outside the mine or minefield, based on human supervision supported by discrimination systems (expert systems, artificial intelligence), swarm intelligence, etc.,
[98] perimetry is understood here as the field of view of technical systems for visual observation,
[99] posts supported by light polarisers against water reflections, underwater cameras fixed and located on underwater vehicles, underwater guarding, etc.,
[100] if they could be inclined to fire at water,
[101] equipment similar to abrasive water jet cutting machines,
[102] such as passive acoustic barriers, magnetic barriers, etc.,
[103] as a rule, the heads of active sonar systems are not directed towards the surface due to interference from wave reflection and interference,
[104] DDS – **D**iver **D**etection **S**onars,
[105] thus, for tactical reasons, the minimum distance limiting the need for covert action should be greater than 800 m,
[106] the use of polarisers improves observation conditions due to the phenomenon of considerable polarisation of the reflected light by the water surface,
[107] for example, by jamming electronic systems, e.g. creating an electromagnetic pulse,
[108] a mode of relatively slow decomposition of explosives that disperse at a rate significantly lower than the speed of sound in the explosive,
[109] for example: by melting down an explosive, incapacitation by electro-technical jamming, shooting with various types of projectiles, cumulative charges, etc.,
[110] for example: detachment by explosion, shooting down, extraction line, etc.,
[111] signal rope on which a diver is suspended; in most cases the signal rope does not fulfil the conditions for a safety rope,
[112] loudspeaker,
[113] in most cases, the wire communication ropes meet the conditions for safety ropes,
[114] sound-powered telephone,
[115] mines with diver detection elements and actuators to prevent detection and deactivation by the diver,
[116] as a rule, the setting for non-removability is not related to the detection of UXO countermeasures implemented by divers, but such a mechanism is also conceivable,
[117] successive, i.e. when a successful process phase can be followed by another or the previous one can be repeated,
[118] **U**nmanned **C**ombat **A**ir **V**ehicle,
[119] satellite reconnaissance requires expensive investment and, as recent Russian experience shows, it is very easy to shoot down a satellite, which, in view of the relatively cheap UCAV technology and the fact that they are difficult to shoot down, provides a rationale for their increasing use,
[120] the concept of manpower was introduced, not soldiers, because there are concepts and limited practice of using animals for these purposes,
[121] **E**xpendable **M**ine **D**isposal **V**ehicle,
[122] **R**emotely **O**perated **U**nderwater **V**ehicle,\
[123] **M**ine **C**ounter**m**easures **V**essel,
[124] **R**igid **I**nflatable **B**oat,
[125] e.g. remotely controlled lifting systems, initiation of explosions or deflagrations, etc.,
[126] wireless communications, electronic navigation systems, electronically controlled devices, etc.,
[127] **I**mprovised **E**xplosive **D**evice,
[128] as compared with detonation, it is a kind of slowed down, due to heat dissipation by conduction and radiation, combustion reaction propagating at a speed much lower than the speed of sound in the reacting material.