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THREAT OF CHEMICAL TERRORISM IN THE UNDERGROUND

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Review article

Abstract: The paper provides a brief description of the Prague Metro focusing on the potential chemical threats by chemical warfare agents. Detailed evaluation of the possibility of abuse of chemical warfare nerve agents is presented in different conditions in the Prague Metro system as simulated by a TEREX computer program. In conclusion, the results are evaluated by a SWOT analysis referring to many domestic scientific works dedicated to the protection of population against the effects of chemical terrorism.

Keywords: Chemical terrorism, chemical warfare agents, terrorist attacks, Prague Metro, Integrated Emergency System.

Introduction

Sustainable development is hardly possible without both internal and external sustainable safety, which is interrelated with other segments of society development. At present, organized crime, with terrorism being its major force, is among the current threats against society. Particularly group terrorism is a serious threat taking on international and global character.

In terms of the terrorists' targets, attacks of all the usual and progressive forms of terrorism may be expected using the chemical, biological, radiological, and nuclear substances (CBRN) against population as well as against all kinds of traffic infrastructure. Underground traffic systems are characterised by closed or semi-closed areas allowing rather limited movement especially if the numbers of passengers increase such as during rush hours. In these periods, such spaces become ideal for terrorist attacks, particularly chemical ones. It is then little surprising that the first large chemical terrorist attack was carried out in the Tokyo subway, which transports about million people commuting daily from the city suburbs (Okumura et al., 1996; Matoušek et al., 2008). It was this attack that became an initial impulse towards increasing population safety and protection. This gave importance to studies on personal protection equipment, resistance of subways to attacks, etc. (Koenig et al., 2007; Angeloudis et al., 2006). Thus, it is possible to find inspiration for protective and preventive measures in countries with extensive underground traffic systems such as in China or Japan which, due to their previous experience and the large numbers of people transported, require high security.

Regardless of how realistic or probable it is in our conditions to expect terrorist attacks, it must be assumed that the Prague underground traffic system called Metro might be among the places potentially threatened by chemical terrorist attacks (Mika, 2013). For this reason, it is necessary to study the possibilities and circumstances of such attacks to be able to counter by preventive, repressive, protective, rescue, liquidation, and corrective measures. As in other countries with underground traffic, in the Czech Republic, too, terrorist attacks are no doubt most likely to be carried out during the morning or afternoon rush hours when the crowd concentration reaches its peak, particularly at junctions and interchange stations.

In providing population with protection against total danger of chemical terrorism, it is important to mention the current international and national legislation. This includes the Chemical Weapons Convention of 1993, Act no. 19/1997 Coll., and Regulation no. 208/2008 Coll., to this Act, which specifies in detail dangerous chemical substances listing the basic conditions of handling highly hazardous substances, defining the amounts of dangerous substances that must be reported and listing the requirements of the structuring of the registration of named substances. It divides the

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substances into several lists according to the danger they pose (Regulation, 2008).

A new type activity was issued in 2013, (STČ-13/IZS *„Response to a Chemical Attack in the Metro“*) focusing on chemical terrorism in the condition of the Prague Metro (STČ, 2013). This is a non-public material created as a result of long tests and experiments, which also makes use of the pivot operation of a simulation of contaminants spreading in the Prague Metro where strong airflows exist with special effects such as air piston effect with the air being pushed out of a tunnel by the train. The document sets a number of tasks and measures to be carried out by the basic and other parts of the Integrated Emergency System (IES) while describing the procedures to be carried out by rescue teams, cooperation between the parts and listing other details of a successful intervention after chemical attack. It is no doubt a unique planning material that may save tens or even hundreds of human lives or substantially protect the health of the attacked and affected people if carried out completely (Konečný, 2013). In October 2014, a large-scale „Metro 2014“ drill was carried out focused on a terrorist attack using chemical warfare agents. The mock-object discovered was a broken bottle with fluid of unknown origin leaking out producing fumes having adverse effects on the health of the passengers in the Metro. The drill was attended by IES units, the Prague Public Transport Company, and other units involved to test their ability to carry out the procedures required by the above-mentioned STČ document.

By its conception and, especially, by its content and scope of the treatment of an emergency, this is a rather special approach to a methodological material for the activity of the Integrated Emergency System parts. It is expected that a potential underground chemical attack will, in addition to the Metro, affect the life of the whole capital (Klouda, 2008). A traffic breakdown in the entire city may be expected because the Prague Metro with its three traffic lines forms the basic and main backbone of the city transport.

Clearly, in our conditions, the inestimable impacts of strikes carried out by suicide terrorists ready to sacrifice their lives because of extreme religion, ethnic, or political fanaticism can be excluded (Mika, 2013). However, this situation may be subject to a dramatic change due to the increasing tourism but also because of the large population migration. It is well known that, at present, certain Muslim communities are coming into existence also in the Czech Republic (Pokorný, 2014) including the building of the basic religious symbols such as Mosques, prayer rooms, and other buildings.

Materials and methods

At the first stage of a study of chemical terrorism in the conditions of the Prague Metro, a thorough analysis was made of the current conditions of the underground traffic system as mentioned in the introduction. Materials and data on the Prague Metro were found in statistical yearbooks, information bulletins of the Prague Public Transport Company, and in technical literature (Statistical Report, 2013; DPP, 2013a; DPP, 2013b; Konečný, 2013).

A SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis was made to analyze the results obtained to evaluate both the external and internal factors affecting the given problem or subject (Management Mania, 2013). The results were shown in a SWOT analysis table (Tab. 5). Also, an analysis was made of the possibilities of misuse and effects of the nerve-paralyzing chemical warfare agents in the conditions of the Prague Metro using a TEREX computer programme described below.

The Prague Metro - present state

At present, the Prague Metro has 57 stations and 57 km of tunnels. The distance between two stations is about 1,000 to 1,200 metres. Every year, it transports about 583,876 passengers, which is 45.02% of the persons transported by the Prague Integrated Transport System, with 1.6 million passengers transported per day on average (Statistical Report, 2013).

As the city develops, so does the Prague Metro where at present construction work is done to extend the A line. There will be four stations on this line one of them being the Motol station in the vicinity of one of the Czech Republic's largest hospitals. Thus, it may be expected that this part of the extended line, too, will be much frequented with a very high number of passengers. The line should be finished and put into operation in late 2014 to early 2015 (DPP, 2013a).

Another approved Prague Metro development plan is a project to build a D line with the construction to be launched in 2016. As on the A line, this line, too, will have a major station in the vicinity of the Krč Hospital where a high passenger concentration can be expected. After the construction of the lines planned is finished, the number of passengers will be increased, which will bring about a higher potential threat that must be taken into account when planning for security measures in proportion to the development of the Metro (DPP, 2013b). Specific technical parameters of the Prague Metro are available at the Prague Public Transport Company, the Metro operator, at the building companies participating in the development, supplying the ventilating systems, and in research papers (Neplechová and Klouda, 2008; Klouda, 2008; DPP, 2015).

According to experts' opinions, as a transport system, the underground is considerably vulnerable (Konečný, 2013). This is mostly because of the great concentration of persons (passengers) both in the aboveground and belowground stations. The access routes such as underpasses and escalators between the aboveground and belowground stations are also crowded. Planting a timed explosive charge with dangerous chemical substance is relatively easy. This facilitates a terrorist attack in a chosen place at a chosen time. It is easy for the terrorists (attackers) to pick a suitable place and time of the attack by inconspicuously and closely observing for several days the pre-selected exposed places crowded with passengers. One of the numerous security measures implemented in the Prague Metro is PROVAS, an anti-chemical early-warning system that can detect chemical substances including chemical warfare agents and send warnings to the relevant IES units. The large complex system of underground structures including critical infrastructures necessitates the knowledge of the vulnerability (ventilating systems, air flowing, etc.) or, on the contrary, of the security of the system, which is dealt with in detail, for example, in papers by Klouda, 2008; Neplechová and Klouda, 2008; Kozubková et al., 2008.

Nerve- paralyzing warfare chemical agents

Following an analysis of the present state of the Prague Metro, it was also important that the study should estimate the potential misuse of the nerve-paralyzing warfare chemical agents with the most serious adverse impact. The most dangerous type of chemical terrorism (chemical attack) that involves mass attack on people leading to a high degree of health and irrecoverable losses, that is, to a large number of symptoms of higher acute intoxication forms, requires high toxicity, particularly acute inhalation toxicity inhalation, that corresponds to the way and forms of its potential use. When judging agents most likely to be chosen by chemical terrorists, we have to take into account both the threats posed by the agent and the ease with such an agent can be dispersed, which is mostly by free evaporation in a transport infrastructure space, which is not necessarily identical with judging the dangerousness of warfare agents because, in a battlefield, these can be dispersed simply by explosion, which, basically, must be seen as considerably less suitable in the Metro (Mika, 2013).

In the paper, the study was only concerned with ways of misuse of nerve-paralysing warfare chemical agents in the conditions of the Prague Metro. To a considerable extent, however, the conclusions can also be applied to underground traffic systems in other large world capitals. As only code names of the warfare chemical agents are used in the sequel, these highly dangerous highly and extremely toxic chemical compounds are listed in the below table. The data in Tab. 1 are taken from Matoušek et al. 2005; Mika, 2013; Marrs et al., 2007; Engman and Cassel, 2002; Mika, 2011a.

Tab. 1 Code and chemical names of nerve-paralyzing chemical warfare agents (CWA) (Source: the author)

Trivial CWA name	CWA code name	CWA chemical name
Sarin	GB	O-isopropyl methylphosphonofluoridate
Cyclosarin	GF	O-cyklohexyl methylphosphonofluoridate
Soman	GD	O-pinakolyl methylphosphonofluoridate
VX agent	VX	O-ethyl S-[2-(diisopropylamino) ethyl] methylphosphonothiolate
VX-R agent (R-33)	R-33	O-isobutyl S-[2-(diethylamino) ethyl] methylphosphonothiolate
Tabun	GA	O-ethyl N,N-dimethyl phosphoramidocyanidate

Calculation methods and SWOT analysis

Modelling of warfare chemical agent spreading depends on numerous factors such as air flowing in the underground space. At present, the authors have access to a TEREX (Terrorist Expert) computer program and have used it to make a rough estimate of the spreading of warfare chemical agents in the conditions of the Prague Metro (T-SOFT, 2012). Although the authors know about the existence of other better suited software tools such as Fluent, which can model flowing in underground spaces (Kozubková, 2008), TEREX is primarily designed to quickly and reliably model contingencies to quickly and correctly design various protective, rescue, liquidation, and other measures (Mika and Patočka, 2007; T-SOFT, 2012). Unlike the free ALOHA (CAMEO, 2013) program, it helps model even nerve-paralyzing warfare chemical agents such as the below listed sarin, soman, and tabun. The choice of these agents was the result of an analysis of their effects in the condition of the Metro (see the results).

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For the calculations, the standard conservative conditions were assumed (the most pessimistic conditions), which means that the worst conditions were assumed for the dispersion of the dangerous chemical substance in the air. A temperature of 20°C, wind speed of 1 m/s, vertical constancy of the inversion atmosphere. Plane as the surface type in the direction of the dangerous chemical substance spreading. Other conditions can be found directly at each toxic chemical substance. A POISON emergency model (TEREX, 2012) was chosen in the TEREX program designed for modelling poisonous substances, that is, nerve-paralyzing warfare chemical agents in this case. Dispersion of the substance through explosion, spraying, etc. was chosen as the way of substance release.

An important result of the evaluation for warfare chemical agents is the degree of threat to persons by these substances (TEREX output). Another important evaluation result is the recommended measurement of the toxic concentration up to a certain distance from the place of attack. As an input value, TEREX uses the area in hectares (ha) of the contaminated region to evaluate warfare chemical agents.

The modelling was carried out only for the selected nerve-paralyzing warfare chemical agents sarin, soman, and tabun, which is due to the limitations of the TEREX program. Thus, the results obtained can only be regarded as rough because the program does not take into account the specific features of an underground transportation system in terms of the flowing of the contaminate air. The Prague Metro as well as other underground systems such as in Europe is characterized by a high speed of air flowing through the tunnels with the flowing becoming even turbulent in places etc. The modelling of the maximum range of the selected agents is described in the Results chapter (Tab. 2, 3, and 4).

Results

Analysis of the potential misuse of warfare chemical agents in the condition of the Prague Metro

Arranging the warfare nerve-paralyzing poisons spread by explosion as is usual in warfare by their dangerousness, which is given by a simultaneous combination of inhalation and percutaneous intoxication, we get an unequivocal result:

- for colder zones, this is the warfare chemical agent sequence: VX - R33 - GD - GB - GA - GF,
- for very warm climatic zone, the order is changed: VX - R33 - GF - GD - GA - GB.

The Prague Metro space may be regarded as a colder (temperate) climatic zone. Dispersion by explosion, however, does not seem to be applicable here, certainly not inside a car and probably in a station either. It may be assumed that the most suitable method of dispersion is free or aided evaporation bringing about dominant inhalation intoxication. In such a case, volatility in addition to toxicity must be taken to consideration as a very significant physical and chemical property of a chemical substance. Under the above circumstances, in terms of danger, the order of the sequence (from the most appropriate to the most inappropriate agent) is substantially different:

- GB - GF - GD - GA - R33 - VX.

Given the above criteria, the strongly toxic while the most volatile sarin (GB) seems to be the most dangerous substance, which is the reason why it will be exclusively considered in the sequel. It is in this way that sarin was probably chosen as *the most suitable* agent for terrorist attacks by Aum Shinrikyo, the Japanese doomsday cult (Okumura et al., 1996; Mika et al., 2007; Mika et al. 2011b). Modelling the leaking of sarin in the real conditions of the Prague Metro had already been done, for example, for transfer stations focusing on issues related to the outlets of ventilation shafts, which may have a major role in spreading a warfare chemical substance (Klouda et al., 2007; Kozubková et al. 2008; Večerková and Klouda, 2009; Klouda et al., 2011).

It is clear that, given the real potential of spreading techniques, but mainly, given the set of the toxic, physical, and chemical properties, the most likely way of intoxication is acute inhalation poisoning. Nerve-paralyzing substances (sarin above all) are used to disable living creatures. Their effects are manifested symptoms of acute inhalation poisoning (miosis, breathing difficulties) or cause death. Even if sarin's effects are very serious, it only ranks third among nerve-paralyzing poisons (killing LCt_{50} 100 mg.min/m^3, disabling Ect_{50} 50 - 75 mg.min/m^3) behind the about three times more toxic soman and the three-to-ten times more toxic VX. However, considering the spreading potential, particularly free evaporation under the given circumstances, then, comparing the volatilities, sarin poses by far the most total danger. The reason is that the maximum concentration (volatility) C^{20}_{max} is 11500 mg/m^3. This is about five times greater than in soman and thousand times greater than in VX. The high volatility of VX was only investigated

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using the spreading technique in the form of aerosol to simultaneously take advantage of its immense toxicity for unprotected skin if possible through an explosion, which can hardly be expected in a terrorist attack in interior spaces. Such a use is only typical for chemical weapon warfare.

From the above, it follows that to reach the dangerous effect of inhalation intoxication by sarin, that is, 50% disabling to killing, the dosage used must be between 50 and 100 mg.min/m^3.

For further calculation, another input parameter must be estimated, which is the actual exposure to the sarin fumes, given by the expected time of stay of the persons in the (contaminated) Metro spaces. Considering the sizes of stations and the frequency of trains varying with lines and time of the day, it can be estimated, that the stay of a passenger or group of passengers is not likely to exceed 5 minutes on average from entering the escalator tunnel to waiting for the train to getting on the car or moving in reverse order. This implies that, given the above values, for an exposure of 5 minutes in the interior of the Metro, the necessary target sarin concentration in vapours will be 10 to 50 mg/m^3. The situation will be somewhat different inside the cars (Klouda et al., 2011). As the size of the Prague Metro is smaller compared to Paris, London, New York, and other megalopolises where the travelling time from one end of a line to the other may exceed one hour, here the travelling times are much shorter. With the tree lines and the central triangle and given the big frequency of passenger changing lines in the central zones, the average time of staying on a car for passengers travelling between the Prague long-distance bus and railway stations, to the Prague airport, and other passengers may be expected to be about 8 to 12 minutes (also from the authors' own experience). If, for simplicity, we choose an exposure time for a Metro car to be 10 minutes, then the target sarin concentration needed for the car interior will be 5 to 25 mg/m^3.

In both the above cases, the target concentrations of warfare chemical agents are only average ones. It is clear that, depending on the method of dispersion, these concentrations will increase step by step and, especially in the case of free evaporation, starting from the zero level. A degree of threat to passengers in the Metro, depending on the way of dispersion, will involve an integral value given by the dynamics of the gradual building of effective concentrations, which must be taken into account when further investigating the ways of chemical attacks. This particularly implies that the initial amounts needed for a given space volume will probably have to be substantially (that is, several times) higher or methods of simple ways of accelerated evaporation will have to be taken into account (Mika, 2013).

Such methods can use the dispersion techniques adequate to the use by terrorists in a confined space, which, however, must not put in danger the chemical terrorists themselves.

Sarin

The below Tab. 2 shows the results of the modelling by TEREX - POISON model (TEREX, 2012) for sarin, calculating the danger to people through this substance and the recommended investigation of the toxic concentration. In the case of sarin, a different way of substance spreading was chosen: evaporation from a puddle (people are threatened by the chemical substance at a substantially shorter range). Such a way of evaluation was no longer used for other warfare chemical agents.

Tab. 2 Potential misuse of sarin for chemical terrorism (Source: the author, T-SOFT)

Scenario code	Contaminated area [ha]	Dispersion: persons endangered by toxic substance within [m]	Recommended investigation of toxic concentration [m]	Evaporation from puddle: persons endangered by toxic substance within [m]	Recommended investigation of toxic concentration
GB 01	0,1	1 200	1 800	500	750
GB 02	0,2	1 900	2 850	575	863
GB 03	0,3	2 600	3 900	650	975
GB 04	0,4	3 300	4 950	725	1 090
GB 05	0,5	4 000	6 000	800	1 200
GB 06	1	6 500	9 700	1 500	2 250
GB 07	2	9 000	13 500	2 500	3 750
GB 08	3	11 000	16 500	3 200	4 550

Soman

The POISON model - warfare chemical agent - tabular model (T-SOFT, 2012). Method of substance release: dispersion (explosion, spraying, etc.). Persons endangered by the substance: see Tab. 3. The recommended investigation of toxic concentration is shown in the below table.

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Tab. 3 Potential misuse of soman for chemical terrorism (Source: the author, T-SOFT)

Scenario code	Contaminated area [ha]	Persons endangered by toxic substance [m]	Recommended investigation of toxic concentration
GD 01	0,1	7 000	10 500
GD 02	0,2	8 700	13 100
GD 03	0,3	10 500	15 800
GD 04	0,4	12 300	18 400
GD 05	0,5	14 000	21 000
GD 06	1	17 500	26 300
GD 07	2	22 000	33 000
GD 08	3	25 500	38 300

Tabun

The POISON model - warfare chemical agent - tabular model (T-SOFT, 2012). Method of substance release: dispersion (explosion, spraying, etc.). Persons endangered by the substance and the recommended investigation of toxic concentration is shown in the below table.

Tab. 4 Potential misuse of tabun for chemical terrorism (Source: the author, T-SOFT)

Scenario code	Contaminated area [ha]	Persons endangered by toxic substance [m]	Recommended investigation of toxic concentration
GA 01	0,1	1 000	1 500
GA 02	0,2	1 700	2 550
GA 03	0,3	2 400	3 600
GA 04	0,4	3 100	4 650
GA 05	0,5	3 800	5 700
GA 06	1	5 200	7 800
GA 07	2	8 500	12 800
GA 08	3	10 500	15 800

Results of the security SWOT analysis for the Prague Metro focusing on the threat of chemical terrorism

Based on the data from the analysis of the present state and from the results of modelling by the TEREX program, a SWOT analysis has been carried out for the conditions of chemical terrorism in the Prague Metro. Its results provide us with an overall view of the present state and a possible development of the situation of threat and security related to the threat of a misuse of dangerous chemical substances. The results of the analysis are shown in Tab. 5.

Tab. 5 SWOT Analysis - Chemical terrorism in the conditions of the Prague Metro (Source: the author)

Strengths (S)	**Weaknesses (W)**
Protective measures - short routes/ intervals, - camera surveillance system, - fire detection system *Transported persons* - number of transported persons less than in other world metropolises, - no round-the-clock operation in the Prague Metro *Preventive activities* - preparation of the IES units, - new type activity for the IES units *Preparedness and operability* - involvement of IZS units, PIT (Prague Integrated Transport) employees , and other stakeholders, - increasing preventive activities, - carrying out drills in the Prague Metro *Chemical terrorism* - less danger of chemical terrorism in the Czech Republic, - monitoring chemical terrorism issues not only in the CR conditions	*Protective measures* - detection of dangerous substances, - large number of easily accessible stations, *Transported persons* - thorough control of all passengers impossible, - large number of passengers mainly in the morning and afternoon hours *Preventive activities* - little experience of the stakeholders *Preparedness and operability* - knowledge and experience of PID experts and employees, - relatively short-term preventive measures applied *Chemical terrorism* - little or no experience of chemical terrorism in the Czech Republic - little opportunity to check all suspicious looking persons in the Metro, - conditions for quick spreading of dangerous substance
Opportunities (O)	**Threats (T)**
Protective measures - regular updating and inspection of security measures, - increasing security mainly in the new stations *Transported persons* - regular statistical data feedback on transported persons, *Preventive activities* - increasing preventive activities, - promoting cooperation between IES units and PIT employees, - measures to prevent access to dangerous substances an stricter control (monitoring) *Preparedness and operability* - training and educating experts and PIT employees together with relevant IES units and other stakeholders, - gaining knowledge and experience from countries with advanced system of underground transport, *Chemical terrorism* - learning from foreign experience	*Protective measures* - budget cuts on protective measures - outdated protective and security measures, possible malfunction in the event of chemical attack *Transported persons* - large number of persons in a relatively small space (cars) - increasing numbers of transported persons *Preventive activities* - little emphasis on preventive measures and increased security, *Preparedness and operability* - no great emphasis put on protection against potential chemical attack *Chemical terrorism* - hitting even at low concentrations of dangerous substance, - increased threat of a terrorist attack in the Czech Republic, - development of new dangerous substances and methods of their spreading

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Conclusion

Chemical terrorism is a serious security threat not only in the Czech Republic, but all over the world. Its imminence and danger is given by many different facts such as the previous experience of actual attacks (Japan), the appearance of new terrorist groups, changes, and reactions to political changes, growing national minorities even in the Czech Republic, religious fanaticism, etc. The requirement of the present time and of the near future is then the need of intensive involvement of governmental intelligence services, which must be constantly occupied by uncovering the preparations of terrorist attacks in order to prevent violence and extortion in cooperation with the police and other public administration bodies.

Concerning the victims of terrorist attacks, these are not only direct victims, dead and wounded persons, but also indirect victims including the families and friends of the victims, and a wider informed public. It is the informed public on which, through the media, the present terrorists count when planning their atrocities to be very brutal to shock the entire public to draw attention to their requirements, attitude to a political situation, etc. Chemical terrorism, which can bring about unfathomable and catastrophic consequences, must be counted to this category, too.

It should be stressed that modelling a chemical terrorist attack along with its devastating impacts is a condition necessary for a thorough scientific investigation in this area.

The data of the SWOT analysis reflect the present state of security and security measures along with the results of the modelling by the TEREX computer programme in the conditions of the Prague Metro. The results provide an overall view of the strengths, weaknesses, threats, and opportunities to strengthen the preparedness, security measures, and prevention. The situation should result in a comprehensively prepared and organized protection of population against chemical terrorism.

In 2013, an important and comprehensive methodology, *Model Activity of the Integrated Emergency System (in reaction to a chemical attack in the Metro)*, was published. Now it is necessary to verify the cooperation and collaboration procedures recommended thoroughly and sensitively in the technical practice, which is only possible in the form of demanding model and comprehensive drills, or in the form of stringent tests of preparedness. The Metro 2014 drill carried out in the much-frequented Anděl station was one of such tests of preparedness for the increasing threat potential in the Czech Republic. The results of this drill will help improve the work of the IES units and increase the security of the critical infrastructure.

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