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Analysis of an Event Related to the Uncontrolled Release of Ammonia from a Rail Tanker

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Summary
Numerical engineering tools are being more and more frequently applied in supporting decisions responsible for rescue operations in terms of tactics and strategy. This elaboration presents one of the applications of such software in the event of uncontrolled releases of hazardous substances. The adoption of numerical modelling as an element which supports leadership results in the reduction of operating costs and affects its performance. The example used will show the potential of these solutions to people unrelated directly to chemical and ecological rescue. It may become a basis for developing drills, including evacuation drills, for people responsible for their planning and organization in the railway structures.

Keywords: chemical rescue, dispersion modelling, ALOHA

1. Introduction

The article presents a practical use of one of the tools deriving from the engineering sciences in rescue operations in terms of tactics and strategy. Liquid and gas steam dispersion modelling is now part of the training for each member-to-be of the National Fire Brigade. Based on one specific study case, the legitimacy of such an approach by those responsible for the curriculum in fire fighter training centres and the operational benefits from the point of view of the rescue operation leader (commander) – KDR [7] are shown. The event dated 21 January 2018 that took place in Kuźnica, where a rail tanker with ammonia began to leak, can be used as the example.

2. Description of the tool – ALOHA

The latest issue of the ALOHA program by CAMEO, an American company, is Version 5.4.7 of September 2016. It allows details concerning the real or potential release of chemicals to be introduced, and then approximate hazard zones to be generated for various kinds of events. With ALOHA, it is possible to model toxic or inflammable gas clouds, BLEVE phenomena (boiling liquid expanding vapour explosion), jet fires, pool fires and explosions of liquid steam clouds [2].

The reflection of the simulation in the program are fields limited by isopleths (lines connecting points of identical value of substance concentration) [5]. Estimations of hazard zones are shown on the grid and can also be presented on maps in MARPLOT®, ArcMap by Esri, Google Earth and Google Maps. Relevant colours stand for hazard levels: maximum (red), and lower hazard (orange and yellow).

In its newest version, ALOHA includes the updated library of chemical substances, elaborated in the American Design Institute for Physical Properties, and new threshold values of concentrations (PAC – Protective Action Criteria for Chemicals and ERPG – Emergency Response Planning Guidelines). Depending on the consequences of their impact on humans without personal protective equipment, the sizes of hazard zones are specified on the basis of the criteria below.

Due to the country of origin of the software, the threshold concentrations are adopted in accordance with definitions and guidelines of the American scientific and research institutes (available threshold concentrations are the following: AEGL, ERPG, PAC and IDLH). There are three AEGL levels (Acute Exposure Guideline Levels) specifying the degree of hazard to the organism when contacting chemical substances, as defined in the following way by EPA (United States Environmental Protection Agency):

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1. AEGL-1 – concentration of a toxic substance in the air (expressed in mg/m^3 or ppm), above which all people in the zone can feel discomfort, irritation or asymptomatic effects of the influence, which are reversible;
2. AEGL-2 – concentration of a toxic substance in the air (expressed in mg/m^3 or ppm), above which all people in the zone will suffer irreversible health impairment;
3. AEGL-3 – concentration of a toxic substance in the air (expressed in mg/m^3 or ppm), above which all people in the zone will be subject to long-lasting and serious health impairment or die.

The model adopts doses based on the test results of the National Research Council's Committee on Toxicology. All three levels (AEGL-1, AEGL-2 and AEGL-3) were developed for five exposure periods: 10, 30 and 60 minutes as well as 4 and 8 hours.

Another hazard scale is ERPG (Emergency Response Planning Guidelines) which includes threshold concentration values to anticipate unfavourable effects for human health caused by exposure of the individual to toxins (American Industrial Hygiene Association's data):
1. ERPG-1– specifies the maximum concentration below which presumably almost all individuals can be exposed to toxins for 1 hour without experiencing other effects than mild, temporary effects unfavourable to human health or undesired and clearly noticeable symptoms;
2. ERPG-2 – specifies the maximum concentration below which presumably almost all individuals can be exposed to toxins for 1 hour without experiencing or developing irreversible or other serious, unfavourable-to-health effects or symptoms which deteriorate individual ability to undertake independent protective actions;
3. ERPG-3 – specifies the maximum concentration below which presumably almost all individuals can be exposed to toxins for 1 hour without experiencing or developing effects which pose a threat to human health [4].

There are also three PAC (Protective Action Criteria) value levels, where every other value is related to stronger and stronger effects of the higher exposure level. In turn, IDLH (Immediately Dangerous to Life or Health) is the highest permissible concentration of steam or gas in the atmosphere at which the presence of individuals devoid of upper respiratory tract and skin protection for 30 minutes does not pose a threat to their health or life (values elaborated by NIOSH – National Institute for Occupational Safety and Health).

The structure of the program allows critical parameters to be adapted for hazardous substance concentrations, with their values included in other standards than American. In Poland, the threshold values of concentrations are described in Polish norms stipulating the top permissible concentration, top short-term concentration, or lethal inhalation dose (LC_{50}).

LC_{50} – median lethal dose – concentration of the substance which, when given through inhalation to test animals for a specific time, causes 50% of the animals in the test group to die.

NDS – top permissible concentration – average weighed value of the concentration whose impact on the employee in the 8-hour daily and average weekly work time, stipulated in the labour code, for the time of his/her professional activity should not lead to negative changes to the health of a person exposed to a specific hazardous substance and the health of future generations.

NDSCh – top short-term concentration – average value of the concentration which should not lead to negative changes to an employee's health if he/she remains in the work environment:
- not longer than 15 minutes and
- not more frequently than twice per work shift, at a time interval of at least 1 hour [3].

An essential change from the point of view of the case in question is the update of the ALOHA model called RAILCAR for pressurized liquid tanks. The improved sub-model is the result of field tests conducted by the Naval Surface Warfare Center, Dahlgren Division, in which the creation of a "suspended" cloud in the form of mist was requested. This allows more precise estimation of the actual emission of a substance from the pressurized tank in the time function. It is highly important while modelling the spread of toxic gas clouds, fires and explosions to specify fields in which the critical values of parameters may be exceeded and the local society may be in danger. The studies were performed with a view to verifying and materializing the impact of ammonia and chlorine from pressure tanks when they are damaged.

3. Specification of the substance released in the case in question

Ammonia explosion limits range from 15 to 28% vol., and the self-ignition temperature is 630°C. Ammonia is a flame-resistant substance, yet in enclosed rooms may form an inflammable or explosive aerosol when contacting air or oxidants. Mercury compounds or hydrocarbon steam, e.g. from greases, serve as catalysts. The release of ammonia in the open air does not lead to explosion risk. Additional hazards are potential breakage of the tank during uncontrolled heating, and large ammonia leakage results in the emergence of a thick mist which limits visibility. When inhaling ammonia vapours, the following symptoms may occur: instant irritation of eyes or upper respiratory tract, as well as coughing and impaired breathing. In addition, short-term contact with high concentrations of ammonia may lead to serious lung damage. There is a risk of death as a consequence of pulmonary edema, even after 48 hours [5, 9].

4. Principles of rescue operation in the face of chemical and ecological hazards

The principles of organizing chemical and ecological rescue in the domestic rescue and fire-fighting system were described in the document drawn up by the National Headquarters of the State Fire Service [10]. The detailed guidelines can be found in Part 5 "General principles of chemical and ecological rescue", Chapter 5.1 "Rescue operations with regard to chemical and ecological rescue".

The above-stated principles show that operations related to chemical and ecological rescue, both basic and specialist, should be performed with special regard to safety rules specified in the applicable OHS regulations. Safety standards in chemical and ecological rescue determine the main safety rules for fire fighters or rescuers. The principle applies to initial conduct when units reach the site, as well as the proper positioning of rescue vehicles.

As far as reasonably possible, it is advisable to ensure suitable access to the site and position vehicles from the windward side on high areas of the land. The minimum distance between people and the source of emission should be the following:

- for any substances which pose a threat of explosion – at least 150 m,
- for substances, items or units which pose a radioactive contamination threat – depending on the radiation power (μSv/h), but not less than 30 m in open land,
- for other cases – at least 50 m.

According to the guidelines given by the National Headquarters of the State Fire Service, it is possible to change initially adopted minimum distances in three cases:

- after performing more precise recognition of the operational situation,
- measurements with the use of proper meters (which allows precise specification of the zone size),
- analysis of the hazardous substance.

When positioning vehicles, it is necessary to anticipate the need to withdraw forces and measures quickly, taking into account the dynamics of the situation.

In the process of assessing the sizes of hazard zones and their potential relocation, weather conditions are considered, that is temperature, rainfall, lightning discharge and others.

The following will also influence the size of zones: existing infrastructure, topography and other land features (e.g. forests).

The second rule applied is the selection of personal protective means adequate to the hazard and circumstances of the event. The selection of the equipment must make allowances for explosive concentrations, oxygen and toxic substances in the surrounding area, properties of the dangerous substance and its resistance to chemical factors.

The priority in rescue operations is the evacuation of people to the designated safe zone. Operations in the hazard zone must be performed by one group of properly trained rescuers and a group of supporters equipped with the same personal protective means with communication between them and the KDR.

In order to limit exposure to hazardous factors, it is necessary to control the time during which fire fighters or rescuers stay in the hazard zone and avoid an extensive number of these professionals in the hazard zone. Depending on the substance released in an uncontrolled way, the area and initial decontamination must be predicted. Intervention must be based on a "10-minute rule" (decision-making process includes changes of the situation 10 minutes in advance). This results from the fact that, in the case of local hazards such as technical failures, the nature of hazards, that is fire, explosions, or dangerous reactions, may change rapidly.

The way of taking the action must lead to the avoidance of redundant exposure of fire fighters or rescuers to the impact of hazardous substances throughout all operations. In the event of chemical contamination, the units involved in the action must include a properly equipped medical support team. During the rescue operation, the leader of the rescue operation may withdraw from rules commonly acknowledged as safe in accordance with applicable regulations.

5. Description of the event

The event took place on 21 January 2018 in the area of a railway siding, which is a place for repairing cargo trains, at the International Railway Border Crossing in Kuźnica. During the customs clearance, at about 10:00 pm, ammonia leakage was confirmed with the use of a multi-gas TX detector. The source of the hazard was a rail tanker with a capacity of 92 m^3 carrying 47.1 tons of odourless ammonia (UN 1005), part of a standard-gauge cargo train composed of 32 tankers and a locomotive. The leak in the tank was probably the result of damage to the emergency opening of the bottom valve of the tanker. The event was classified as a local moderate hazard (chemical, in railway communication) on the surface space of 70,000 m^2 [8].

First, fire prevention units from OSP KSRG Kuźnica came to the site at 10:28 pm. The situation (deployment of the cargo trains) is depicted in Fig. 1.

No injured individuals were found on the site. After inspection, rescue operations were initiated. They ended on 24 January 2018 at 7:00 am, which accounts for the total intervention time of about 58 hours.

In direct recognition, noticeable frost was found to signal a potential ammonia leak (under the bottom valve of the tanker). When checking the damaged tanker with the use of detectors, the ammonia concentration in the range 20–40 ppm was measured in the immediate vicinity of the bottom valve, while at a distance of about 30–50 cm from the valve – no emission was recorded. The value of the temperature determined with the use of a thermal imaging camera was –7°C. During further works on the valve located under the bottom valve of the tanker, a minor leak of the vapour phase or drops of liquid phase of ammonia was periodically found – short-term concentration at the bottom valve rose to the value of about 100 ppm, but the maximum hazard zone did not exceed 0.5 m.

The endangered area contained residential buildings, so having designated the safety zone with a radius of 150 m, people were evacuated. The adoption of such a distance arose directly from [10]. Based on this decision in the first stage of operations, the estimation was to evacuate people from about 15 residential buildings. In the face of unfavourable weather conditions, the operation could have been risky, with the potential need to evacuate people from a large area of Kuźnica.

Once the rescue operation leader had come to the site, the operation area was divided into two operational sectors (OS):

- The first OS covering the place of direct rescue operations in the premises of the Polish National Railways – actions taken by JRG Sokółka and Specialist Chemical Rescue Group "Białystok" COO of C level,
- The second OS covering part of Tadeusz Kościuszko Street, intended for the evacuation and protec-

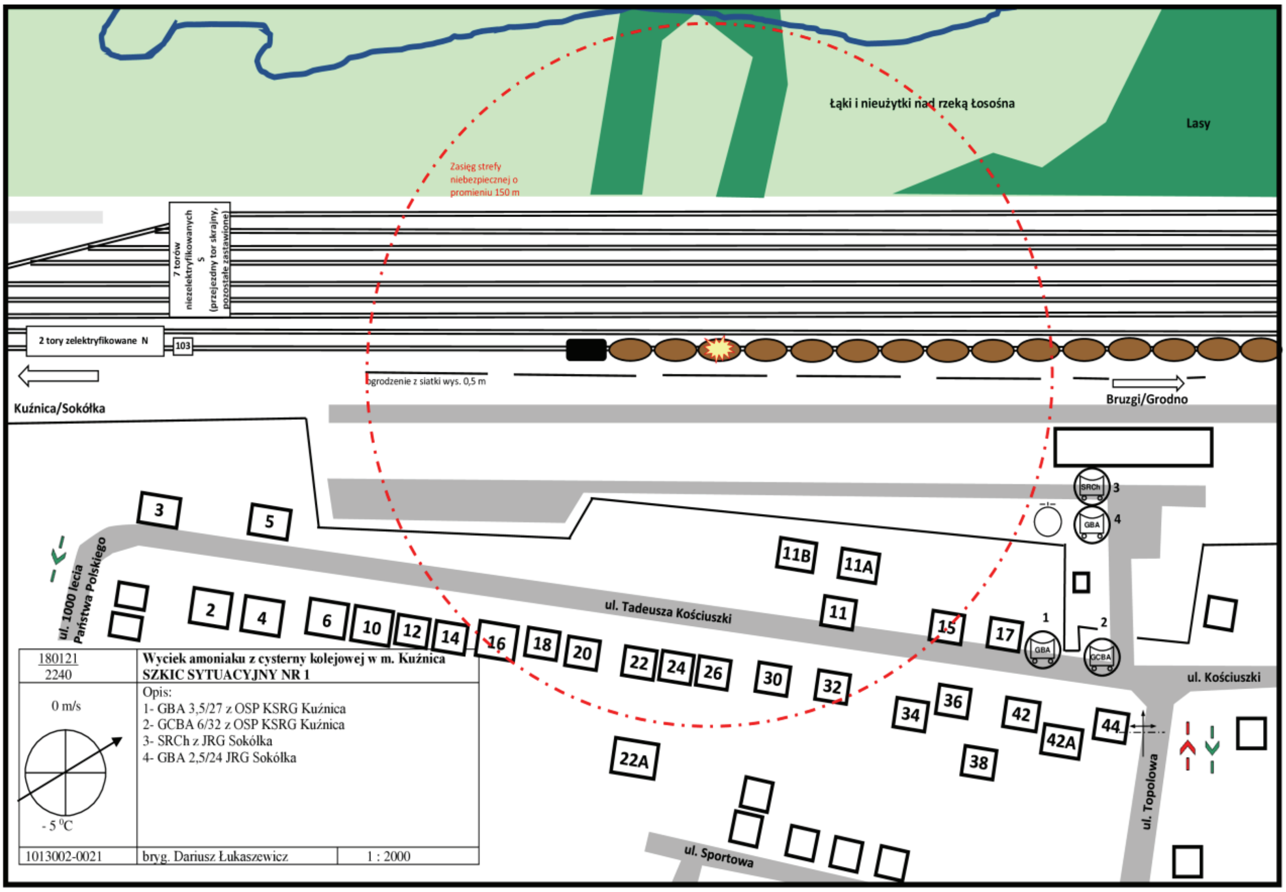
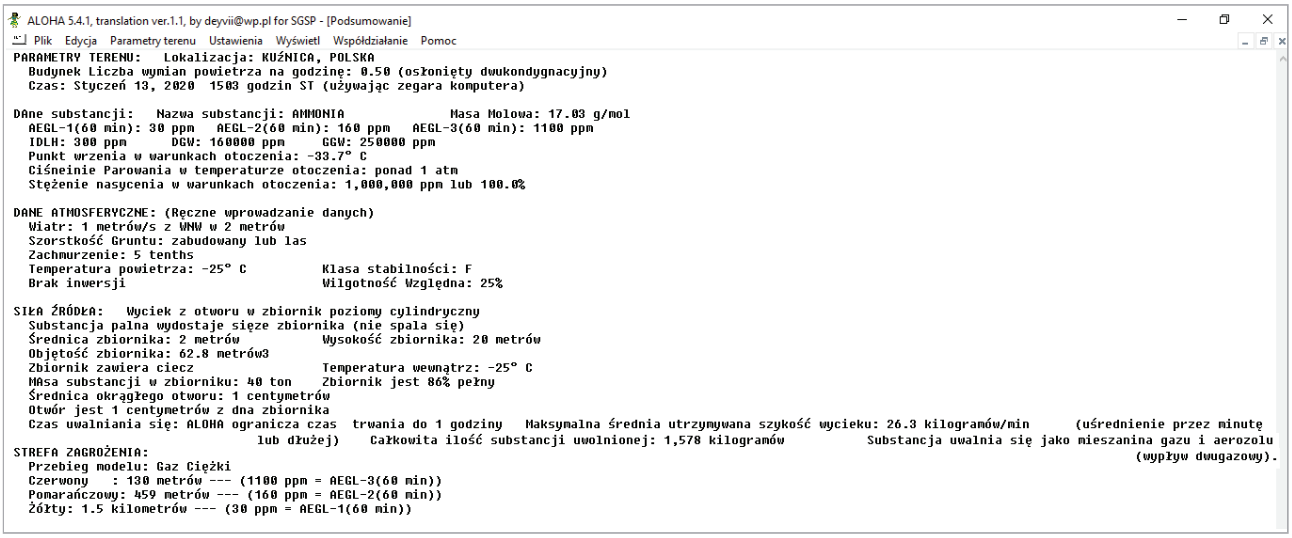


Fig. 1. Ammonia leakage from the rail tanker in Kuźnica – site plan [8]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ALOHA 5.4.1, translation ver.1.1, by deyvii@wp.pl for SGSP - [Podsumowanie]
Plik  Edycja  Parametry terenu  Ustawienia  Wyświetl  Współdziałanie  Pomoc
PARAMETRY TERENU:   Lokalizacja: KUŹNICA, POLSKA
  Budynek Liczba wymian powietrza na godzinę: 0.50 (osłonięty dwukondygnacyjny)
  Czas: Styczeń 13, 2020  1503 godzin ST (używając zegara komputera)

DAne substancji:   Nazwa substancji: AMMONIA              Masa Molowa: 17.03 g/mol
  AEGL-1(60 min): 30 ppm   AEGL-2(60 min): 160 ppm   AEGL-3(60 min): 1100 ppm
  IDLH: 300 ppm      DGW: 160000 ppm     GGW: 250000 ppm
  Punkt wrzenia w warunkach otoczenia: -33.7° C
  Ciśneinie Parowania w temperaturze otoczenia: ponad 1 atm
  Stężenie nasycenia w warunkach otoczenia: 1,000,000 ppm lub 100.0%

DANE ATMOSFERYCZNE: (Ręczne wprowadzanie danych)
  Wiatr: 1 metrów/s z WNW w 2 metrów
  Szorstkość Gruntu: zabudowany lub las
  Zachmurzenie: 5 tenths
  Temperatura powietrza: -25° C          Klasa stabilności: F
  Brak inwersji                          Wilgotność Względna: 25%

SIŁA ŹRÓDŁA:   Wyciek z otworu w zbiornik poziomy cylindryczny
  Substancja palna wydostaje sięze zbiornika (nie spala się)
  Średnica zbiornika: 2 metrów           Wysokość zbiornika: 20 metrów
  Objętość zbiornika: 62.8 metrów3
  Zbiornik zawiera ciecz                 Temperatura wewnątrz: -25° C
  MAsa substancji w zbiorniku: 40 ton    Zbiornik jest 86% pełny
  Średnica okrągłego otworu: 1 centymetrów
  Otwór jest 1 centymetrów z dna zbiornika
  Czas uwalniania się: ALOHA ogranicza czas  trwania do 1 godziny   Maksymalna średnia utrzymywana szykość wycieku: 26.3 kilogramów/min      (uśrednienie przez minutę
                              lub dłużej)    Całkowita ilość substancji uwolnionej: 1,578 kilogramów          Substancja uwalnia się jako mieszanina gazu i aerozolu
                                                                                                                                   (wypływ dwugazowy).
STREFA ZAGROŻENIA:
  Przebieg modelu: Gaz Ciężki
  Czerwony   : 130 metrów --- (1100 ppm = AEGL-3(60 min))
  Pomarańczowy: 459 metrów --- (160 ppm = AEGL-2(60 min))
  Żółty: 1.5 kilometrów --- (30 ppm = AEGL-1(60 min))
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Fig. 2. Input data entered into ALOHA software [elaborated by operations staff, jr brig. Marcin Anszczak – operational group KW PSP Białystok]

tion against access of third parties – operations performed by OSP KSRG Kuźnica units.

In order to designate hazardous zones more precisely, on 22 January 2018 the appointed operation staff made calculations and forecast the expansion of the zone in the event of uncontrolled leakage of ammonia with the use of ALOHA software. The input parameters entered into the model are presented in Fig. 2.

Using the results of calculations, the KDR decided to limit the hazard zone. A visual model of the simulation results is shown in Figures 3 and 4.

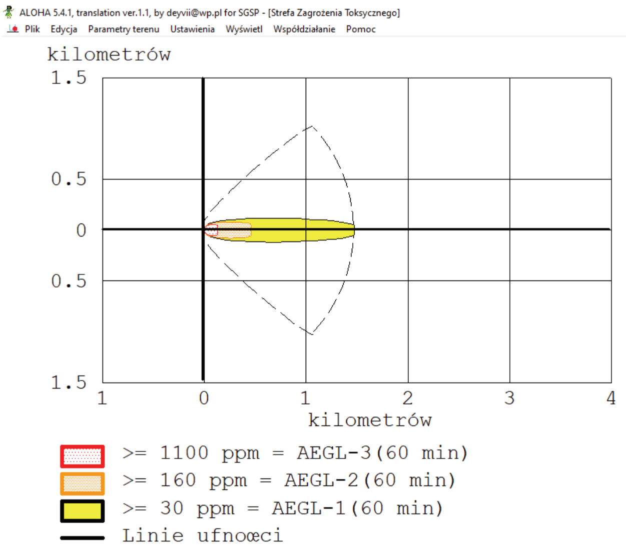

Fig. 3. Simulation result in the ALOHA program (threshold limit values as per AEGL), [elaborated by operations staff, jr brig. Marcin Anszczak – operational group KW PSP Białystok]

Additionally, the option of transferring isopleths into a real terrain map was used.

Thanks to the decision to limit the hazard zone on 22 January 2018 at 2:00am, residents were allowed to return to their homes, while operational sectors were eliminated. Another positive aspect of using numerical modelling was approval for the resumption of the rail cross-border traffic.

6. Summary and conclusions

The gravity of the issue in question can be assessed through the State Fire Service intervention statistics analysis. To illustrate, there were 109 events on the cargo rail in 2019 (i.e. freight cars and tankers). Therefore, relevant rescue forces (fire fighters and rail technical rescue) must be properly prepared for their elimination, and their deployment must ensure access to the accident site in a relatively short time.

Previous events related to ammonia leakage from rail tankers in Kuźnica took place on 6 March 2002 (about 100 kg of ammonia leaked from tankers on drain valves) and on 26 August 2002 (about 5 kg of ammonia leaked from a tanker on drain valves). In turn, on 10 April 2003 the remaining LPG leaked from a broad-gauge rail tanker after unloading.

An uncontrolled release of a dangerous substance (LPG gas), which entailed serious consequences, occurred on 8 November 2010 in Białystok, where the surface space of the fire covered about 5,000 m^2. Two diesel locomotives, nineteen tankers, two freight cars and a signalling control building caught fire. Thanks to the fire fighters' operations, it was possible to save

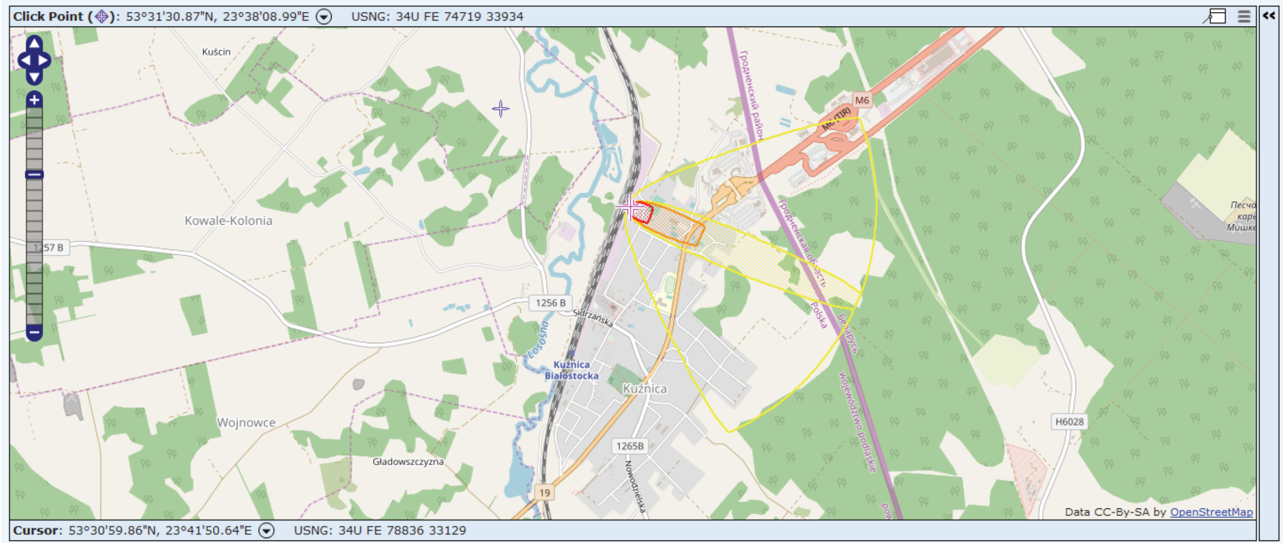

Fig. 4. Simulation result in the ALOHA program (threshold limit values transferred into a real terrain map) [elaborated by operations staff, jr brig. Marcin Anszczak – operational group KW PSP Białystok]

two buildings belonging to PKP PLK, twelve tankers with oil-derivative products, two LPG tankers and a few dozen rail cars from trains involved in the event and parked on neighbouring tracks [7].

The elaboration proves the legitimacy of the use of advanced engineering tools in supporting decisions made by the rescue operations leader. The materialization of potential hazards arising from the release of the hazardous substance (ammonia) led to the commitment of forces and means of KSRG from the Podlaskie Province being limited, the return of residents to their homes and the resumption of international rail traffic. Aside from the purely human aspect, that is the limitation of evacuation of third parties being out of the hazard zone, the economic aspect of rescue operations and their broad consequences is very important. Maintenance of an enlarged personnel and equipment status on the site, where it is necessary from the point of view of hazard monitoring, does not only mean costs pertaining to employee remuneration and the use of vehicles and devices. It also causes KSRG intervention capabilities (operational readiness) to weaken in the event of other circumstances, such as fires and local hazards in the operational area of units. Similarly, the resumption of rail traffic before the final end of operations has a considerable impact on the financial consequences of the event. The saved amounts are not only those directly related to operational costs. The early end of rescue operations has an influence on the value of contractual penalties arising from the failure to meet delivery deadlines for rail carriers. Such delays may result in disturbed production at the recipient's, as well as increased rental costs of rail vehicles. This is why the assignment of an officer experienced in operating physiochemical phenomena modelling programs should be a permanent element of planning, included in the operating procedures at tactical and strategic levels.

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