Exposure to carbon monoxide is a common hazard in firefighting practice throughout the year, regardless of the winter heating season. Therefore this analysis of the interventions of fire protection units in incidents related to carbon monoxide exposure of a non-fire origin. The objectives include two risk groups: people affected by the intervention and the health risks to fire officers themselves. The analysed material covers the years 2017-2022 and interventions of fire protection units in incidents related to carbon monoxide exposure of a non-fire origin (chemical hazard events). Data from the Decision Support System of the State Fire Service (DSSSFS), provided to the authors by the Operational Planning Office at the Headquarters of the State Fire Service, were used in the study. According to the records of the State Fire Service (SFS) in the years 2017-2022, there were 28,766 (Mean 4794; SD 413) chemical hazard events: carbon monoxide was the cause. There were only 5724 reports of symptoms with a known CO concentration and 1974 reports with clinical symptoms. Statistically significant differences were demonstrated in exposure time (p= 0.028) and average CO concentration in the analysed years (p<0.001). Noteworthy is the sudden reduction in the exposure time following the year 2020. The actual exposure of firefighters to carbon monoxide is greater than in the above analysis, in addition, there are exposures from fire incidents. Procedures, measuring equipment, and personal protective equipment protect firefighters from absorbing harmful substances into the body, but the large number of incidents and the visible clinical symptoms in victims should prompt firefighters with many years of service to observe even the smallest worrying neurological changes in themselves.

**Keywords:** Carbon monoxide, CO exposure, health hazards for officers, rescue and firefighting operations
INTRODUCTION

It is estimated that carbon monoxide (CO) is the leading cause of inhalation poisoning worldwide. As an odorless and colorless gas, it remains undetectable by human senses, does not irritate mucous membranes, nor stimulates sensory organs, hence it cannot be recognized by them until detected by measuring devices or the appearance of clinical symptoms of poisoning. Often, it is only a feeling of unwellness that raises suspicion. Severe CO poisoning causes multi-organ disorders, later treated in intensive care units. Symptoms of CO poisoning are non-specific, ranging from mild (headache, nausea, weakness, confusion) to severe (loss of consciousness, cardiac dysfunction, respiratory distress, death) (Rataj 2019; Centralny Instytut Ochrony Pracy 2007).

The autumn-winter (heating) period is a time of frequent poisonings in residential buildings due to faulty ventilation, intentional actions of users regarding the covering of ventilation ducts, or various physicochemical and meteorological phenomena reducing ventilation efficiency (Nieścior 2013).

In recent years, an increased number of interventions by entities of the National Firefighting and Rescue System (KSRG) in incidents related to carbon monoxide during prolonged heatwaves has been observed. On days when the outdoor air temperature is very high, roofs, chimneys, and ventilation ducts heat up. Warm air accumulates in them, resulting in the formation of so-called air cushions in the ducts. Hindered evacuation of exhaust gases causes harmful compounds, mainly CO, to enter living spaces (Naranowicz 2022).

Exposure is defined as the physical contact of a living organism with a biological, chemical, or physical agent, expressed in concentration or intensity as well as duration. During exposure, the chemical substance is taken in and absorbed through various routes. Inhalation poisoning by carbon monoxide is the cause of hospitalization of over 5,000 people annually in Poland (Krzyżanowski et al. 2014).

Contact with carbon monoxide can be classified into several subgroups of inhalation poisonings, including acute, chronic, accidental, and deliberate. The number of exposures in Poland exceeds the European average. In recent years, thanks to preventive measures (educational campaigns in media, schools, and educational activities conducted by the State Fire Service), a decline in fatal poisonings caused by CO has been observed. However, this level remains very high, expressed in thousands of people (Bolechała & Strona, 2013; Krzyżanowski et al. 2014).

In the case of inhalation poisoning in the practice of the National Firefighting and Rescue System (NFRS), the priority is to interrupt exposure by evacuating the victim from the danger zone, then removing the source or cause of carbon monoxide emission, ventilating, and verifying the effectiveness of the actions using measuring devices. Fire protection units (FPU), included in the NFRS, carry out rescue operations at the level of Qualified First Aid (QFA). Various FPU entities cooperate with each other in different protected areas, according to their
established purpose and assigned tasks, have medical equipment, and follow procedures, including cases of victims exposed to inhalation poisoning (Komen-da Główna Państwowej Straży Pożarnej 2021, Rozporządzenie Ministra Spraw Wewnętrznych i Administracji, 2017, Gałązkowski et al., 2014).

Objective
The aim is to analyse the interventions of fire protection units in incidents related to carbon monoxide exposure of non-fire origin. The objectives include two risk groups: people affected by the intervention and the health risks to officers.

MATERIAL AND METHODS
The analysed material covers the years 2017-2022 interventions of fire protection units in incidents related to carbon monoxide exposure of non-fire origin (chemical hazard events). Data from the Decision Support System of the State Fire Service (DSSSFS), provided to the authors by the Operational Planning Office at the Headquarters of the State Fire Service, were used in the study. The analysed material covers the years 2017-2022. The analysis included data from the digital DSS SFS. The event register is maintained in accordance with the Headquarters of the SFS guidelines (Biuro Planowania Operacyjnego Komendy Głównej Państwowej Straży Pożarnej 2022).

Ethical considerations
Data concerning victims, personnel composition of FPU units, cooperating services during interventions, and precise event locations have not been disclosed in the analysis, which is fully anonymous, consistent with the principles of the Helsinki Declaration; therefore, no request was made to an ethics committee for opinions and consent to conduct the study.

Data Analysis
The database was prepared in Microsoft Excel using the MS Office 2016 package for Windows 10. Descriptive statistics were used to characterize the variables. For quantitative variables, the following measures were calculated: mean (Mean) and standard deviation (SD). For categorical variables, the following measures were calculated: number (n) and frequency (%). The data were examined for statistical significance among groups. There were two categorical independent variables which could differentiate the results – symptoms and location described in the report. The numeric parameters evaluated in this study were potential exposure time and measured CO concentration. The statistical analysis was conducted using SciPy, a statistical analysis package of the Python programming language (Virtanen et al., 2020). The comparison of mean values between categories could be done using analysis of variance (ANOVA). The ANOVA requires homoscedasticity across all groups, which was tested using Bartlett’s test (Fisher et al., 1990). The null hypothesis of homoscedasticity
across all groups had to be rejected at p<0.05 in all comparisons, hence the ANOVA was replaced with the Kruskal-Wallis test, a non-parametric equivalent of ANOVA. The Kruskal-Wallis test was used to decide whether there are statistical differences between ranks in groups using the value of H statistics. This test was followed by multiple comparisons Dunn’s test with Bonferroni adjustment, used to determine pairwise, for which groups it is possible to reject the hypothesis of similarity of groups. All these tests are included in the SciPy package except the Dunn’s test which was imported from the scikit-posthocs package (Terpilowski, 2019).

Inclusion criteria for analysis:
- date of intervention between 1.01.2017 00:00 and 31.12.2022 23:59
- interventions in events: local hazards (LH) chemically marked with a “carbon monoxide” flag, which allows the analysis of events with confirmed presence of carbon monoxide using detection and measurement devices equipped in NFRS units.

Exclusion criteria from analysis:
- interventions outside the specified date range
- fire events (F), in which there is a risk of exposure to CO from the thermal decomposition of fuel burned outside heating devices, i.e., places designated for burning. In such events, CO is a component of the mixture of toxic combustion products (fire gases).

Limitations
Clinical information about the condition of the victims (symptoms of CO exposure) was not possible to collect in many cases. The report prepared by the rescue operation leader (ROL), a formation that is not the leading service in medical operations, often lacked detailed medical event details. Information on symptoms post-exposure and precise location occurs only in 26.7% of all events (Tab. 2), and the level of carbon monoxide during the intervention was described in 30% of reports (Tab. 3). The event card after the intervention is prepared by authorized persons, over which the authors had no influence. The analysis does not contain information about the treatment of the injured persons because the DSS SFS system does not cover data from medical entity interventions and hospital treatment.

RESULTS
According to the records of the State Fire Service (SFS) in the years 2017-2022, there were 28,766 (Mean 4794; SD 413) chemical hazard events: carbon monoxide was the cause (Fig. 1). The data show that the nature of these types of operations has been increasing in the last two years of the analysis, with an annual value exceeding 5,000 interventions.

The monthly distribution of events (Table 1) was divided into two periods: heating vs non-heating. The non-heating period was considered as May-Septem-
ber due to Poland’s location in the temperate climate zone. Additionally, the lack of precise regulations regarding the heating period in Poland (due to local differences in average daily temperature, building managers decide on the heating period) was noted. Monthly exposures were supplemented with data divided by days of the week, and on an hourly cycle (Fig. 2).

The Venn diagram provided in Figure 3 presents number of incidents with reported location, reported symptoms and reported CO concentrations allowing to show how many incidents had reported were in the intersection. The values can be read as follows: symptoms were reported in 1783 incidents (735+384+251+413) while symptoms and location in 635 incidents (384+251) and symptoms, location and CO concentration in 251.

The boxplots' whiskers have maximum length of 1.5 interquartile range while the outliers are not plotted on graph.

There were only 5724 reports of symptoms during with known CO concentration and 1974 reports with clinical symptoms. The values of statistics for these sets shows that there are significant differences in both CO concentrations and potential exposure among the groups. The Dunn’s test results show that there are only significant differences in CO concentration for observing unconsciousness (Fig 4, left panel) while other pairs there are no statistical differences.
Fig. 2. Chemical Interventions Carbon Monoxide broken down by Days of the Week, and Hours

Table 2. General Characteristics of Reports Containing Information: Location of Exposure, Poisoning Symptoms

<table>
<thead>
<tr>
<th>Local / Year</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kitchen</td>
<td>25</td>
<td>31</td>
<td>55</td>
<td>56</td>
<td>80</td>
<td>99</td>
</tr>
<tr>
<td>Bathroom</td>
<td>402</td>
<td>560</td>
<td>652</td>
<td>638</td>
<td>909</td>
<td>1181</td>
</tr>
<tr>
<td>Livingroom</td>
<td>18</td>
<td>34</td>
<td>45</td>
<td>30</td>
<td>60</td>
<td>71</td>
</tr>
<tr>
<td>Other *</td>
<td>76</td>
<td>102</td>
<td>143</td>
<td>124</td>
<td>152</td>
<td>181</td>
</tr>
</tbody>
</table>

Symptoms

<table>
<thead>
<tr>
<th>Symptom</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vomiting</td>
<td>26</td>
<td>31</td>
<td>50</td>
<td>49</td>
<td>82</td>
<td>79</td>
</tr>
<tr>
<td>Fainting</td>
<td>19</td>
<td>30</td>
<td>32</td>
<td>24</td>
<td>33</td>
<td>39</td>
</tr>
<tr>
<td>Unconscious</td>
<td>81</td>
<td>123</td>
<td>69</td>
<td>93</td>
<td>128</td>
<td>158</td>
</tr>
<tr>
<td>Headache</td>
<td>67</td>
<td>118</td>
<td>145</td>
<td>113</td>
<td>174</td>
<td>211</td>
</tr>
</tbody>
</table>

Figure 3. The Venn’s diagram of incidents with CO. The numbers present the shared values between sets
Figure 4. The dependence between symptoms reported in SWD and measured CO concentration (left panels) and potential exposure time (right panel).

Figure 5. The dependence between location and measured CO concentration (left panels) and potential exposure time right panel.)
Table 3. Univariate comparison of health hazard for officers during intervention

<table>
<thead>
<tr>
<th>Year</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
<th>AllGroups</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Events</td>
<td>368 ±279</td>
<td>363 ±219</td>
<td>402 ±195</td>
<td>389 ±153</td>
<td>422 ±198</td>
<td>454 ±184</td>
<td>399 ±203</td>
<td>0.624</td>
</tr>
<tr>
<td>Exp. time</td>
<td>56±2</td>
<td>58±3</td>
<td>58±3</td>
<td>55±3</td>
<td>55±3</td>
<td>55±3</td>
<td>56±3</td>
<td>0.028</td>
</tr>
<tr>
<td>CO (ppm)</td>
<td>22±8</td>
<td>36±9</td>
<td>41±8</td>
<td>31±11</td>
<td>33±8</td>
<td>38±13</td>
<td>34±11</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>
The highest significance, was in CO concentration between group with unconsciousness and headache. It confirms that higher concentrations led to unconsciousness while lower cause only headache. The concentrations causing vomiting also are statistically different from unconsciousness, while there is observed but not statistically significant difference in concentrations between group with fainting and with unconsciousness. All the remaining pair did not show differences, was very close to 1. The same case was with the potential exposure (PE) (statistically different at p<0.01).

Dangers to the officers’ health during interventions were estimated on the basis of 2 parameters that were available in the databases: intervention time, number of intervening units. The results are presented in Table 3, and Figs. 6 and 7.

Statistically significant differences were demonstrated in exposure time (p=0.028) and average CO concentration in the analysed years (p<0.001). Noteworthy is the sudden reduction in exposure time after the year 2020. Starting from 2017, statistically significantly higher CO concentrations during rescue interventions were demonstrated.

**DISCUSSION**

Preventive measures against carbon monoxide exposure include public campaigns carried out by state institutions. Among them are those related to inhalation poisoning, for example, “CARBON MONOXIDE AND FIRE – AWARENESS”, “DETECTOR ON GUARD FOR YOUR SAFETY”. Public campaigns are implemented through media broadcasts, online services, and directly by the State Fire Service officers in workplaces, schools, or educational rooms “FLAME” (Kubiak et al, 2022; Komenda Główna Państwowej Straży Pożarnej).

The first symptoms depend on the concentration of CO in the air and the duration of exposure. The initial symptoms manifest in the nervous system (headaches, dizziness, nausea, vomiting, balance disorders, vision disturbances). A complete clinical picture of the causes of exposure is provided by symptoms, complemented by a medical interview and examinations such as blood morphology, imaging diagnostics (Zwierzyńska et al. 2014; Mensah-Kane & Sumien, 2023).

The difficulty in quickly diagnosing CO poisoning lies in the symptoms, which in the early stages of poisoning are attributed to other causes: alcohol intoxication, flu, migraine, infection, heatstroke. In our own analysis, we focused on selecting clinical character information from the descriptive part of reports: symptoms of exposure. Our results concerning the symptoms of poisoning of the affected people, involved in the interventions, align with other analyses. Fainting, loss of consciousness, nausea, and vomiting are classic symptoms of CO exposure (Pham et al, 2019; Barros, Oliveira & Morais, 2021).

A firefighter is a profession with an increased risk of CO poisoning, especially chronic complications, due to the repetitive risk of exposure. Over many years of service, they are exposed to carbon monoxide and other harmful substances.
hundreds of times. These are short-term exposures, as firefighters are equipped with air composition meters. Before the detection and measurement device signals the presence of threshold concentrations of CO or other harmful levels in the breathing atmosphere, everyone exposed in the hazard zone is likely to take several breaths, allowing the substance to enter the body (Długosz & Bogaczyk, 2009).

Firefighters who intervened in the events covered by the analysis were exposed to CO for a correspondingly shorter time than the users of the residential unit. The potential exposure time of firefighters is reduced by the stages of alert, travel to the site, and threat recognition (making measurements). However, repeated contact with harmful compounds in the body may cause a cumulative effect of individual doses and lead to late complications such as neurodegenerative diseases. Besides respiratory exposure, firefighters also experience skin absorption of volatile substances, for example, when staying in an endangered environment not related to firefighting activities, as in our own analysis (Tomaszek et al. 2022; Drellich et al., 2012).

Due to frequent exposures to harmful substances that may accelerate neurodegenerative diseases, firefighters undergo annual medical examinations, including consultations with many specialists, including neurological consultations. Positions exposed to harmful factors mainly within Rescue and Firefighting Units (RFU) are subjected to examinations to detect abnormalities. In the organizational units of the State Fire Service, registers of harmful health factors present at the workplace are maintained, as well as records of examinations and measurements of harmful factors, in accordance with applicable laws (Rozporządzenie Ministra Zdrowia 2011; Rozporządzenie Ministra Spraw Wewnętrznych i Administracji 2005).

Lembas-Bogaczyk concludes in her study that CO in firefighter practice is a cause of neurological injury and despite the treatment, neuropsychiatric complications limiting efficiency arise. Studies on the causes of diseases among firefighters serving in the RFU conducted in Poland show that diseases of the nervous system and sensory organs accounted for 18.5% of the illnesses (Lembas-Bogaczyk, Długosz & Tokarczyk, 2011).

The analysed data on firefighter interventions did not include information on exposures that caused symptoms. However, one cannot deny firefighters’ exposure considering the average duration of interventions and the average level of carbon monoxide measured by firefighters (Tables 3).

The causes of the events covered by the analysis are mainly inefficient ventilation, inadequate exhaust of combustion gases from heating installations, or faulty heating devices. One of the factors of lack of ventilation is the deliberate action of room users (Fig. 8).

Our results show that a greater number of exposures occur during the heating season. In the summer months, heating installations are used to heat water. Annually in Poland, there is a meteorological phenomenon that can affect summer exposures. The African anticyclone is a meteorological phenomenon involving
the influx of hot air into the temperate climate zone. The general characteristics of such a system involve initiating descending currents, which heat and dry the air. Under these conditions, roofs, chimneys, and ventilation ducts heat up, resulting in a lack of draft in chimney flues. As a result, combustion gases penetrate into residential premises (Wołoszyn 2009; Godłowska 2019; Komenda Główna Państwowej Straży Pożarnej).

CONCLUSIONS

Exposure to carbon monoxide is a common hazard in firefighting practice throughout the year, regardless of the heating season. The actual exposure of firefighters to carbon monoxide is greater than in the above analysis, in addition, there are exposures from fire incidents. Procedures, measuring equipment, and personal protective equipment protect firefighters from absorbing harmful substances into the body, but the large number of incidents and visible clinical symptoms in victims should prompt firefighters with many years of service to observe even the smallest worrying neurological changes in themselves.

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Rozporządzenie Ministra Zdrowia z dnia 2 lutego 2011 r. w sprawie badań i pomiarów czynników szkodliwych dla zdrowia w środowisku pracy. (Dz. U. 2019 r., poz. 995).


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