Tendencies in the propagation of fires and ammunition explosions at fixed storage facilities

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Abstract. Aim. To suggest an approach to identifying the common features of statistical series containing information on the time, place and external conditions of the development and propagation of emergency situations associated with fires and ammunition explosions at fixed storage facilities, to synthesize the function of partial risk indicator of such situations, i.e., the energy susceptibility to external effects of ammunition storage systems. Methods. The paper uses methods of mathematical analysis of statistical series and probability theory. For the first time ever, individual external conditions of emergency situations involving ammunition are analysed using statistical series (rate of insolation). Results. The paper has collected and classified statistical data on emergencies involving fires and explosions in ammunition storage facilities that took place in the current century in a number of countries of the world, whose emergency nature was confirmed by extensive media coverage. Using statistical series analysis, an exponential relationship has been established between the rate of fires and explosions and the total power saturation of the ammunition storage system. Conclusions. The frequency of emergencies involving fires and explosions depends on the overall power saturation of the storage system that is defined by the solar intensity in the area of the ammunition storage facility that depends on its latitude and season. The suggested approach allows, by analysing empirical data on the time and place of emergencies, identifying the specific survivability values of a hazardous storage facility characterizing the energy susceptibility of the system to the effects that trigger explosions and fires.

Keywords: ammunition, explosives, fire, explosion, factor, arsenal, survivability.

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Introduction

The emergency of any phenomena of the real world is determined by comparing them with similar phenomena on the basis of the frequency of their onset and the extent of the transformation of the environment in the course of such events. The trends in the occurrence of rare events with potentially major consequences are the subject matter of the risk theory. The quality of risk assessment and analysis defines the efficiency of the management of complex potentially hazardous systems, including missile and ammunition storage facilities.

Today, along with analytical models, simulation, event and solution tree analysis, heuristic methods of knowledge acquisition, neural network programming and learning are widely used for assessing the risks associated with the behaviour of complex systems. The validity of the estimates obtained using a certain method of analysis of phenomena and synthesis of scientific knowledge depends on the quality and amount of the obtained information (initial data) and the quality of the analysis and synthesis mechanism. The higher is the number of factors taken into account as part of risk analysis, the more valid is the system behaviour model and higher is the accuracy of risk assessment. This approach allows synthesizing the emergency risk function in the form of a multiplicative convolution of partial indicators \( r_i \):

\[
R(t_1, ..., r_1, ..., r_n) = \prod_{i=1}^{n} f_i(t_i).
\]

In addition to the man-made, technology-related and natural factors that characterize the probability of events able to cause emergencies, the overall level of system susceptibility to energy effects that define the probability of emergency propagation in time and space should be examined as an additional partial indicator of the risk function.

In many previous studies [1-10], based on statistical data, the underlying causes of such fire and explosion emergencies (FEE) were analysed. This paper deals with environmental energy conditions that contribute to the propagation of fires and explosions. The primary source of energy for all processes on the Earth’s surface is the radiant energy of the Sun called solar radiation. The energy of stellar radiation and heat coming to the surface of the Earth as the result of the processes taking place within it are negligible compared to solar radiation [11]. The formation of organic matter that constitutes the basis of combustible and explosive materials is essentially the process of accumulation in the course of billions of years of biotransformation of the primary source of energy within the molecular bonds of the substrate.

The purpose of the paper is to identify new correlations between a system’s energy saturation and the frequency of FEEs at ammunition storage facilities.

1. Problem definition

The ability of explosive and flammable materials to initiate cascading combustion and explosions of other substances underlies the potential hazard of ammunition storage facilities. Stored ammunition is essentially accumulators of destructive energy connected by potential initiation relationships. The damage caused by the destructive operation of such energy depends on the energy potential of the chemical elements in the ammunition, the energy potential of the fire load at the storage facility (crating, structures, vegetation) and the degree of loss of control over the energy release. Thus, the level of emergency of the ammunition fires and explosions is defined not only by the level of intentional control input, but by the intrinsic properties of the system, its energy capacity. It is obvious that if a system’s energy saturation is zero (absolute zero temperature), no chemical processes within materials are possible. Another boundary condition for the onset and propagation of FEEs is the energy saturation of the system reaching energy-releasing reaction in organic materials. For black powders, ignition becomes possible after hours-long exposure to temperatures in excess of 400° K. Thus, the frequency of explosions and fires at each storage facility is supposed to depend on the energy input into the system. Under known boundary energy conditions of reliable or impossible onset of the event of explosion and fire initiation, it is required to define the function of the effect of a system’s energy saturation on the frequency of explosions and fires in order to determine the partial indicator of risk, i.e., the system’s susceptibility to energy effects.

2. Overview of previous research

Normally, FEE is a consequence of factors of intentional or unintentional human influence (man-made factor), errors or failures of technology (technology-related factor) and stochastic natural effects (natural factor). Each of these factors depends on the spatiotemporal characteristics of the system.

In [1-9], it is noted that the “human factor” dominates in the causality of FEE. Thus, in [6], based on the analysis of a large set of statistical data, it is noted that the number of technology-related fires following a temperature increase goes down \( r = – 0.72 \), while the number of fires due to social causes increases \( r = 0.73 \) instead. The number of fires caused by other factors is not associated with temperature dynamics.

The yearly distribution of incidents was examined in [1, 2]. Those works identified trends for higher frequency of incidents in fire hazard periods. For instance, out of 73 FEEs at ammunition storage facilities examined in [2] 93% took place during the warm season from March to October. The authors attribute that to the fact that most scheduled activities involving ammunition are carried out during the warm season, whereas they start in May and the end in October.
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[2, p. 32]. However, it should be noted that as the ambient temperature rises, within the system, the intensity of chemical processes increases, the energy threshold of initiation of combustion and explosion reactions decreases and the fire load on the storage facility premises grows. Thus, growing energy saturation of the system affects the frequency of explosions and fires.

3. Definition of input data

Achieving the designated goals involved examining the distinctive features of FEE development identified as part of the analysis of publicly available statistical data on the time, place and external conditions of mass explosions of ammunition at fixed storage facilities in a number of countries starting from 01.01.2001. The very fact that information on such incidents was covered in the media allows qualifying them as “extraordinary” and indicates that the examined energy connections are manifest in the sequence of mass explosions and fires.

The environmental temperature and humidity, the rates of thermal currents and static voltage in the air masses that affect the explosion and fire safety of the storage system, depend on the radiant energy of the Sun. The causality is clear: high temperature and low humidity dry out the fire load in the FEE area and increase the sensitivity of the explosives and powders to the initiating effects; the flows of oxygen-rich air facilitate the combustion reaction; the static voltage discharges, forming lightnings of hot plasma.

Almost all (90%) the radiation energy from the Sun is received by the Earth at the upper boundary of the atmosphere [11]. The amount of heat delivered by solar radiation per 1 cm² of a surface perpendicular to the beams of sunlight per 1 min of time is called solar intensity and is determined using the formula:

\[ I = S/4\pi r^2, \]

where: \( S \) is the radiating power (radiant emittance) of the Sun equal to about 4·10^{26} MW; \( r \) is the distance between the Earth and the Sun.

Given the average distance between the Earth and the Sun \( r = 149.600 \) mil km, the solar intensity is 1.98 cal/(cm²·min) or 1.37 kW/m². This value is called the solar constant.

The energy spectrum of solar radiation at the boundary of the atmosphere is close to that of the absolutely black body with the temperature of about 6000 K.

The distribution of solar radiation at the outer fringe and its change over time depend on the following causes:

1. Solar activity. In the peak years, the power of solar radiation can increase by 2%. As the solar activity grows, the Earth experiences increased intensity of magnetic and ionospheric disturbances affecting the man-made and technology-related factors of FEE;

2. Distance between the Earth and the Sun. Since the Earth’s orbit is an ellipse, in January, the distance \( r_1 = 147.100 \) mil km, while in July, \( r_2 = 152.100 \) mil km. On the day of the winter solstice, the solar intensity is about 3.3% stronger than in spring and autumn, while on the day of the summer solstice it is 3.3% weaker.

3. The incident angle. The amount of incoming solar radiation (insolation) changes over time due to the deviation of the earth axis from the perpendicular to the orbit plane by 23°30’.

Thus, the cause of the annual and daily cycles of atmospheric phenomena is the rotation of the Earth around the Sun and the inclination of the Earth. If we designate the solar elevation as \( h_0 \), then a unit of the horizontal surface receives as much less radiation, as the surface area is larger than the flow area.

The solar intensity delivered to a surface at an angle of \( h_0 \) equals

\[ I_s = I_o \sin h_0, \]

where: \( I_o \) is the rate of solar radiation per 1 min per 1 cm² of a perpendicular surface, \( h_0 \) is the flow incident angle. From astronomy, it is known that

\[ \sin h_0 = \sin \varphi \sin \delta + \cos \varphi \cos \delta \cos \psi \cos, \]

where \( \varphi \) is the site latitude; \( \delta \) is the solar declination; \( \psi \) is the local hour angle of the Sun.

Consequently, the heat inflow from solar radiation to a horizontal surface depends on:

1. Site latitude \( \varphi \) that largely defines the differences between the climate zones;

2. Solar declination \( \delta \) that changes during the year from \( \delta = 23.44^\circ \text{N} \) to \( \delta = 23.44^\circ \text{S} \), which defines the seasons;

3. Local hour angle of the Sun \( \psi \) that defines the daily variation of the solar intensity;

4. Distance between the Earth and the Sun \( r \).

For the purpose of the analysis of the parameters of the evaluated system, the geographical coordinates of the potentially hazardous facilities are the initially specified spatial characteristics.

The values of the solar declination (\( \delta \)), time of sunrise and sunset for specific dates can be determined using the solar calculator: http://www.timezone.ru/suncalc.php.

With an error of ±0.2º, the solar declination is calculated using the known formula (Wikipedia):

\[ \delta = -\arcsin(0.39779 \cos(0.98565(\text{N}_a-N_0))+1,914^\circ \sin(0.98565(\text{N}_a-N_0))) \]

where: \( N \) is the sequence number of the estimated day from January 1; \( N_0 \) is the number of days since the December solstice before January 1 \((N_0 = 10)\); \( N_a \) is the number of days after January 1 before the perihelion \((N_a = 2)\).

The local hour angle of the Sun \( \psi \) is related to the latitude and solar declination with the formula:

\[ \psi = \arccos(-\text{tg} \varphi \times \text{tg} \delta). \]
Table 1. Emergencies associated with fires and ammunition explosions

| No. | Site | Latitude φ (degrees) | Date | JDN | Daily insolation Q (MJ/m²) |
|-----|------|----------------------|------|-----|--------------------------|
| 1   | Desselbrunn, District of Vöcklabruck, Austria | 48.02 | 01.02.2018 | 32 | 12.635 |
| 2   | Shirvan, Azerbaijan | 39.92 | 26.07.2016 | 208 | 40.022 |
| 3   | Gilzi, Khizi District, Azerbaijan | 40.87 | 27.08.2017 | 239 | 34.957 |
| 4   | Zemelan, Albania | 41.32 | 06.05.2006 | 126 | 38.043 |
| 5   | Gërdec, Albania | 41.42 | 15.03.2008 | 75 | 26.792 |
| 6   | Ain Defla, Algeria | 36.32 | 18.10.2015 | 291 | 24.974 |
| 7   | Bashgah, Afghanistan | 34.52 | 02.05.2005 | 122 | 38.331 |
| 8   | Parwan, Afghanistan | 35.02 | 23.03.2006 | 82 | 31.135 |
| 9   | Chelopeche, Bulgaria | 42.70 | 03.07.2008 | 185 | 41.771 |
| 10  | Kostenets, Bulgaria | 42.27 | 08.08.2014 | 220 | 38.144 |
| 11  | Kostenets, Bulgaria | 42.27 | 20.03.2015 | 79 | 27.434 |
| 12  | Iganovo, Bulgaria | 42.67 | 04.04.2015 | 94 | 31.076 |
| 13  | Kazanlak, Bulgaria | 42.62 | 25.04.2016 | 116 | 36.007 |
| 14  | Magilizh, Bulgaria | 42.60 | 27.05.2016 | 148 | 40.776 |
| 15  | Hamburg, Germany | 53.55 | 30.08.2002 | 242 | 30.118 |
| 16  | Aden, Yemen | 12.78 | 28.03.2015 | 87 | 37.158 |
| 17  | Maharashta, India | 21.27 | 31.05.2016 | 152 | 39.728 |
| 18  | Port of Tanjung Priok, Indonesia | -1.08 | 05.03.2014 | 64 | 37.934 |
| 19  | Baghdad, Iraq | 33.35 | 06.06.2018 | 157 | 41.279 |
| 20  | Tokrau, Kazakhstan | 46.83 | 08.08.2001 | 220 | 37.371 |
| 21  | Arys, Kazakhstan | 42.43 | 20.03.2009 | 79 | 27.358 |
| 22  | Karao, Almaty Region, Kazakhstan | 43.52 | 08.06.2009 | 159 | 41.596 |
| 23  | Otar Station, Kazakhstan | 43.55 | 27.08.2013 | 239 | 34.237 |
| 24  | Arys, Kazakhstan | 42.43 | 26.06.2014 | 177 | 41.994 |
| 25  | Arys, Kazakhstan | 42.43 | 24.06.2019 | 175 | 42.012 |
| 26  | Hengyang, China | 26.97 | 18.06.2014 | 169 | 40.848 |
| 27  | Mbuji-Mayi, Democratic Republic of the Congo | -5.50 | 26.01.2014 | 26 | 38.373 |
| 28  | Maputo, Mozambique | -25.23 | 22.03.2007 | 81 | 34.061 |
| 29  | Lagos, Nigeria | 6.45 | 27.01.2002 | 27 | 34.254 |
| 30  | Podali, Khabarovsk Krai, Russia | 50.55 | 17.01.2001 | 17 | 8.715 |
| 31  | Nerchinsk, Chita Oblast, Russia | 51.98 | 22.06.2001 | 173 | 41.797 |
| 32  | Gusinoye Ozero, Buryatia, Russia | 51.12 | 20.07.2001 | 201 | 39.885 |
| 33  | Syzran, Samara Oblast, Russia | 53.17 | 10.07.2002 | 191 | 40.881 |
| 34  | Snegovaya Pad, Primorsky Krai, Russia | 43.12 | 16.10.2002 | 289 | 21.853 |
| 35  | Khabarovsk, Russia | 48.48 | 13.06.2003 | 164 | 41.711 |
| 36  | Norsk, Amur Oblast, Russia | 52.33 | 18.06.2003 | 169 | 41.721 |
| 37  | Kiparisovo, Primorsky Krai, Russia | 43.47 | 13.07.2003 | 194 | 41.207 |
| 38  | Achkhoy-Martan, Chechen Republic, Russia | 43.18 | 07.12.2004 | 342 | 12.168 |
| 39  | Kronstadt, Russia | 60.00 | 17.05.2005 | 137 | 36.768 |
| 40  | Ulan-Ude, Republic of Buryatia, Russia | 51.83 | 16.06.2005 | 167 | 41.683 |
| 41  | Yuzhnye Koryaki, Primorsky Krai, Russia | 53.27 | 01.10.2005 | 274 | 20.459 |
| 42  | Lodeynoye Pole, Leningrad Oblast, Russia | 60.73 | 23.05.2008 | 144 | 38.208 |
| 43  | Fokino, Primorsky Krai, Russia | 42.97 | 30.09.2008 | 274 | 25.822 |
| 44  | Karabash, Chelyabinsk Oblast, Russia | 55.48 | 14.09.2009 | 257 | 24.647 |
| 45  | Ulyanovsk, Russia | 54.32 | 13.11.2009 | 317 | 8.711 |
| 46  | Ulyanovsk, Russia | 54.32 | 23.11.2009 | 327 | 7.089 |
| 47  | Arga, Amur Oblast, Russia | 51.27 | 28.10.2010 | 301 | 14.053 |
| 48  | Dachny, Lipetsk Oblast, Russia | 52.62 | 06.04.2011 | 96 | 27.590 |
| 49  | Urman, Bashkortostan, Russia | 55.47 | 26.05.2011 | 146 | 39.297 |
| No. | Site                                      | Latitude φ (degrees) | Date       | JDN | Daily insolation $Q$ (MJ/m²) |
|-----|-------------------------------------------|----------------------|------------|-----|-----------------------------|
| 50  | Pugachiovo, Udmurtia, Russia              | 56.60                | 02.06.2011 | 153 | 40.199                      |
| 51  | Surgach, Primorsky Krai, Russia           | 45.52                | 18.05.2012 | 139 | 39.480                      |
| 52  | Koltubanovsk, Orenburg Oblast, Russia     | 49.02                | 11.06.2012 | 163 | 41.639                      |
| 53  | Orlovka, Orenburg Oblast, Russia         | 48.83                | 09.10.2012 | 283 | 20.290                      |
| 54  | Chapayevsk, Samara Oblast, Russia        | 52.98                | 18.06.2013 | 169 | 41.689                      |
| 55  | Bolshya Tura, Zabaykalsky Krai, Russia   | 51.62                | 29.04.2014 | 119 | 34.384                      |
| 56  | Pugachiovo, Udmurtia, Russia             | 56.60                | 04.05.2015 | 124 | 34.270                      |
| 57  | Urman, Bashkortostan, Russia             | 55.47                | 03.06.2015 | 154 | 40.432                      |
| 58  | Yuganets, Nizhny Novgorod Oblast, Russia | 56.23                | 04.08.2016 | 217 | 36.005                      |
| 59  | Samara, Russia                           | 53.18                | 18.10.2016 | 292 | 15.238                      |
| 60  | Khalino, Kursk Oblast                    | 51.73                | 21.04.2017 | 111 | 32.268                      |
| 61  | Galichny, Khabarovsk Krai, Russia        | 50.72                | 29.07.2017 | 210 | 38.522                      |
| 62  | Primorskoye, Abkhazia (Russian Base)     | 42.58                | 02.08.2017 | 214 | 39.017                      |
| 63  | Pugachiovo, Russia                       | 56.60                | 16.05.2018 | 136 | 37.198                      |
| 64  | Kamenka, Krasnoyarsk Krai, Russia        | 56.27                | 05.08.2019 | 217 | 35.997                      |
| 65  | Zheltukhino, Ryazan Oblast, Russia       | 53.75                | 07.10.2020 | 281 | 19.063                      |
| 66  | Parachin, Serbia                         | 43.97                | 19.10.2006 | 292 | 20.621                      |
| 67  | Deir ez-Zor, Syria                       | 35.33                | 08.10.2017 | 281 | 27.710                      |
| 68  | Damascus, Syria                          | 33.52                | 02.09.2018 | 245 | 35.600                      |
| 69  | Abu Dali, Syria                          | 34.43                | 14.06.2019 | 165 | 41.596                      |
| 70  | Mashrua ad-Dummar, Syria                 | 33.52                | 15.06.2019 | 166 | 41.547                      |
| 71  | Shayrat, Syria                           | 34.48                | 03.08.2019 | 215 | 39.559                      |
| 72  | Rmelan, Syria                            | 36.48                | 21.06.2020 | 173 | 41.824                      |
| 73  | Al-Hasakah, Syria                        | 36.48                | 16.07.2020 | 198 | 40.995                      |
| 74  | Novaki, Slovakia                         | 48.72                | 03.03.2007 | 62  | 19.452                      |
| 75  | Juba, Sudan                              | 4.85                 | 23.02.2005 | 54  | 36.607                      |
| 76  | Sagamihara (US base), Japan              | 35.57                | 24.08.2015 | 236 | 36.663                      |
| 77  | Letterkenny, USA                         | 39.93                | 19.07.2018 | 200 | 40.815                      |
| 78  | Abadan, Turkmenistan                     | 38.05                | 08.07.2011 | 189 | 41.544                      |
| 79  | Diyarbakir, Turkey                       | 37.90                | 16.09.2015 | 259 | 31.608                      |
| 80  | Kilis, Turkey                            | 36.72                | 13.07.2017 | 194 | 41.250                      |
| 81  | Hakkarî, Turkey                          | 37.57                | 09.11.2018 | 313 | 19.621                      |
| 82  | Reyhanlı, Turkey                         | 36.27                | 09.08.2019 | 221 | 38.739                      |
| 83  | Kogon District, Bukhara Region, Uzbekistan| 39.72                | 10.07.2008 | 192 | 41.407                      |
| 84  | Artemivsk, Luhansk Oblast, Ukraine       | 48.60                | 10.10.2003 | 283 | 20.421                      |
| 85  | Novobogdanovka, Zaporizhzhia Oblast, Ukraine | 47.05              | 06.05.2004 | 127 | 37.235                      |
| 86  | Novobogdanovka, Zaporizhzhia Oblast, Ukraine | 47.05              | 23.02.2005 | 54  | 18.258                      |
| 87  | Tsvitokha, Khmelnytskyi Oblast, Ukraine  | 50.23                | 06.05.2005 | 126 | 36.363                      |
| 88  | Novobogdanovka, Zaporizhzhia Oblast, Ukraine | 47.05              | 19.08.2006 | 231 | 35.058                      |
| 89  | Lozova, Kharkiv Oblast, Ukraine          | 48.88                | 27.08.2008 | 240 | 32.352                      |
| 90  | Svatove, Luhansk Oblast, Ukraine         | 49.40                | 29.10.2015 | 302 | 14.941                      |
| 91  | Geyevka, Ukraine                         | 49.50                | 08.03.2016 | 68  | 20.719                      |
| 92  | Khmelnytskyi, Ukraine                    | 49.42                | 22.07.2016 | 204 | 39.658                      |
| 93  | Balakliia, Kharkiv Oblast, Ukraine       | 49.45                | 23.03.2017 | 82  | 24.865                      |
| 94  | Mariupol, Ukraine                        | 47.12                | 22.09.2017 | 265 | 26.280                      |
| 95  | Kalynivka, Vinnytsia Oblast, Ukraine     | 49.43                | 26.09.2017 | 269 | 24.000                      |
| 96  | Balakliia, Kharkiv Oblast, Ukraine       | 49.45                | 03.05.2018 | 123 | 35.887                      |
| 97  | Ichnya, Chernihiv Oblast, Ukraine        | 50.85                | 09.10.2018 | 282 | 19.436                      |
| 98  | Gazost, France                           | 43.02                | 07.10.2003 | 280 | 24.229                      |
| 99  | Salawa, Sri Lanka                        | 6.92                 | 05.06.2016 | 157 | 36.159                      |
| 100 | Latacunga, Ecuador                       | -0.27                | 07.11.2016 | 312 | 37.136                      |
The distance between the Earth and the Sun \( r \) is determined using the formula
\[
r = \frac{r_0 \left(1 - E^2\right)}{1 - E \cdot \cos \left(\frac{\pi}{2} - \arcsin \frac{\sin \delta}{\sin \varepsilon}\right)},
\]
where: \( r_0 = 149.6 \) mil km is the average distance between the Earth and the Sun, \( E = 0.0167 \) is the Earth’s orbit eccentricity, \( \arcsin \frac{\sin \delta}{\sin \varepsilon} \) is the Sun’s geocentric longitude.

Calculating all the arguments that affect heat inflow allows determining the daily insolation in FEE area on the day of occurrence \( Q \) by the formula:
\[
Q = \frac{I_0 T}{\pi \left(r/r_0\right)^2} (\psi \sin \phi \sin \delta + \cos \phi \cos \delta \sin \psi),
\]
where: \( Q \) is the total daily insolation, MJ/m\(^2\); \( I_0 \) is the solar constant equal to 1.37 kW/m\(^2\);

\( T \) is the period of the Earth’s daily rotation (equal to 86 400 s).

Table 1 shows the input data and calculated daily insolation values for each FEE site and time.

The spatiotemporal distribution of the analysed set of FEE is shown in Fig. 1.

**4. Determining the dependence of the FEE rate of the energy saturation**

Certain values of daily insolation in the area of storage facilities at the moment of FEE enable statistical analysis based on this energy feature of the general population of exploded storage facilities (see Fig. 1).

The frequency distribution of 100 FEEs by daily insolation is presented in Fig. 2.

The power approximation of the integral indicator of FEE frequency with the insolation thresholds with the certainty of \( R^2 = 0.9976 \) allows estimating the dependence of the prob-
ability of explosions and fires from the energy saturation of the environment.

Thus, the conducted analysis of empirical data allowed synthesizing the function of the partial risk indicator, i.e., a system’s energy susceptibility to external effects, expressed through the value of daily insolation in a certain geographical region at a certain time

\[
r_e = \frac{0.0103 \cdot Q_{\text{max}}^{0.534}}{0.0103 \cdot Q_{\text{max}}^{0.534}} = \left(\frac{Q}{44}\right)^{0.534}.
\]

The physical meaning of this indicator can be interpreted as the degree of correspondence of the environmental energy conditions with the conditions that most favour the development of FEEs.

Subject to the proposed partial risk indicator, the synthesized function of FEE risk \((r_e)\) will be the product of four components:

\[
r_e = r_{va}^a \cdot r_{vai}^b \cdot r_{ae}^c \cdot r_{ve}^d,
\]

where: \(r_{va}\) is the stock value indicator (affects the choice of the target of attack); \(r_{vai}\) is the stock vulnerability indicator (affects the attack effectiveness); \(r_{ae}\) is the indicator of social climate in the FEE area (indicates the aggressiveness of the social environment); \(r_{ve}\) is an indicator of energy susceptibility (reflects the aggressiveness of the environment for the FEE development).

The specificity of using the convolution of indicators as multipliers is due to the fact that the human perception of expected losses has a logarithmic scale. In addition, the use of multiplicative convolution does not allow setting the partial indicators themselves that may have a natural expression, while only setting their weight coefficients: \(a, b, c, d\).

### 5. Discussion of the results

A number of reasons can be associated with a rapid growth of the frequency of incidents as the insolation increases.

1. High-energy radiation (nuclear radiation) causes changes in the properties of powders. When affected by such radiation, destruction and structuring processes occur within them, ions and radicals may be generated that sharply increase the rate of chemical stabilizer consumption [5].

2. The cause of increased EA sensitivity to rising temperature is the weakening inter-molecular binding within the substance that facilitates the propagation of the initiating effects of wave, kinetic and thermal nature. As the temperature rises, the time it takes to heat the wooden package and gunpowder/ammunitions to combustion temperature decreases, the depth of fragments penetration into the protective structures increases, wave attenuation in the environment weakens.

3. The power law dependence of the FEE on the level of insolation can be due to biological causes: growing fire load in ammunition storage facilities, intense growth and drying of vegetation, as well as the above-noted growing rate of operations involving ammunition. The existence of a dependence between the above and the comfortable climate conditions of work activity is beyond doubt.

4. Growing FEE frequency with rising insolation may be due to climate-related causes, e.g., increased frequency of thunderstorms, forest fires, peat fires, etc.

### Conclusion

The conducted analysis of statistical data on incidents that caused fires and explosions at ammunition storage facilities allowed revealing a correlation between growing FEE frequency with rising environment temperature and the power law dependence of the susceptibility of items in the system to external effects on the overall energy saturation of the external environment.

The susceptibility to external effects reflects the correspondence between the actual external energy conditions and those that are most favourable for the propagation of FEE. This indicator should be used as an adjusting coefficient of the integral FEE risk indicator.

The inconsistency of the obtained findings regarding the effect of the environmental energy saturation on the emergencies involving ammunition explosions and regarding the low level of correlation between the frequency of forest fires and the air temperature stated in [6 – 9] defines the requirement to further examine the differences in the ways the environment’s energy characteristics affect the more stochastic processes of mutual initiation of explosions and the more deterministic processes of fire front propagation.

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The author’s contribution

Based on statistical data on emergencies involving ammunition fires and explosions in a number of countries of the world, the author suggested an approach to identifying the common features of statistical series containing information on the time, place and external conditions of the development and propagation of emergency situations associated with ammunition fires and explosions at fixed storage facilities and synthesized the function of partial risk indicator of such situations, i.e., the energy susceptibility to external effects of ammunition storage systems, identified the dependence between the rate of fires and explosions and the overall power saturation of an ammunition storage systems.

Conflict of interests

The author declares the absence of a conflict of interests.