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Satbayev University

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ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
РЕСПУБЛИКИ КАЗАХСТАН
Satbayev University

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IMPROVING THE SYSTEM FOR RESPONDING TO FIRE IN AREAS CONTAMINATED BY THE CHERNOBYL DISASTER

Abstract. Based on the analysis of statistical data on fires in the territory of the Exclusion Zone, a growing trend in their number has been established, and has a dependence close to linear. The fire and man-made danger of the territory of the Exclusion Zone, as well as the existing fire and rescue units, have been identified. The distribution of calls by service time was calculated and it was found that fire and rescue units are most involved in the time intervals from 1 to 2 hours and from 7 to 8 hours, with the average service time of one call is about 4 hours. Based on the data of the calculation table of the least squares method, for the first time, an equation of the functional dependence of the predictive calculation of the number of fires for the next year on the territory of the Exclusion Zone was obtained and the tendency for an increase in the number of fires was confirmed. It has been established that the existing fire and rescue units of the Exclusion Zone provide a proper response to a fire in only one third of the territory. In this regard, additional fire and rescue units were proposed with the mapping of service areas on the map according to certain criteria.

Key words: exclusion zone, fire response, service time of one call, fire and rescue unit, location.

Introduction. The number of fires increases annually on the territory of the exclusion zone and unconditional (obligatory) resettlement (hereinafter referred to as the Exclusion Zone). This, in turn, increases the number of tasks assigned to fire and rescue units stationed in the Exclusion Zone. The operational environment of the Exclusion Zone creates a set of conditions in a given period of time that promote or prevent the occurrence, development and elimination of man-made and natural emergencies (primarily fires). One of the features of extinguishing fires on the territory of the Exclusion Zone is the work of firefighters in conditions of radiation pollution. The fire safety in these territories is significantly affected by the wooded area and the scanty number of fire and rescue units, including forest fire posts, unevenly located throughout the territory. This requires special attention, since it has a decisive influence on the process of fire development and, accordingly, on the caused material damage.

To date, the domestic regulatory framework for determining the number, deployment and maintenance of fire and rescue units of the territory of the Exclusion Zone has not been regulated, since the established requirements in [1, 2, 9] do not take into account its specifics.

Methods for determining the number of fire and rescue units are described in various literature sources [3 - 5]. Each of them has its own characteristics.

A well-known method for determining the number of personnel of fire and rescue units is presented in the manual [6]. It is based on the standards for performing certain work, depending on the complexity of the fire, but does not take into account certain factors that affect the ability to determine the number of forces and means of operational calculation. In the literature [7, 8], attention is paid to the characteristics of fire extinguishing means, but a full-fledged comprehensive methodology for determining forces and means, which can be used in the conditions prevailing on the territory of the Exclusion Zone, is not defined.

The analysis of literary sources has shown that among the existing approaches to determining the forces and means necessary to extinguish fires, none of them can be directly applied to the realities of the exclusion zone. And the gaps in the current regulatory framework do not make it possible to apply standardized approaches to determining the number of fire and rescue units and their service areas in the Exclusion Zone.

The purpose of the work is to improve the fire response system on the territory of the Exclusion Zone on the basis of substantiation of the required number of fire and rescue units (forest fire stations) and their service areas. To achieve this goal, it is necessary to solve the following tasks:

- to establish the fire, man-made danger of the territory of the Exclusion Zone and the number of fires over the past 5 years;
- to determine the available fire and rescue units in the territory of the Exclusion Zone;
- calculate the average service time of one call;
- on the basis of a discrete variation series, to establish the distribution of fire-fighting and rescue vehicles attraction for extinguishing fires;
- develop a forecast of the number of fires for the next year;
- to estimate the locations of the existing fire and rescue units on the territory of the Exclusion Zone and provide proposals on the locations for the creation of new fire departments.

Materials and methods. 2.1. General data on fires in the Chernobyl exclusion zone

Today the area of the Exclusion Zone reaches over 259 thousand hectares. The distribution of the territory of this zone is shown in Figure 1.

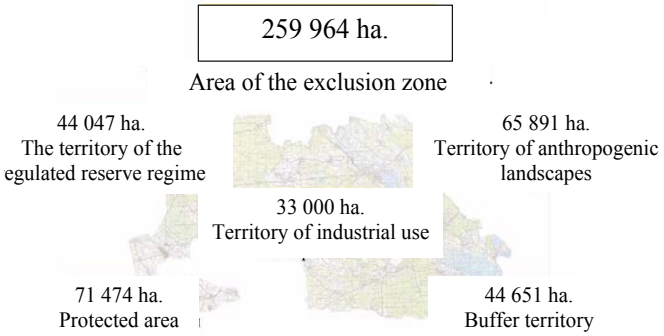
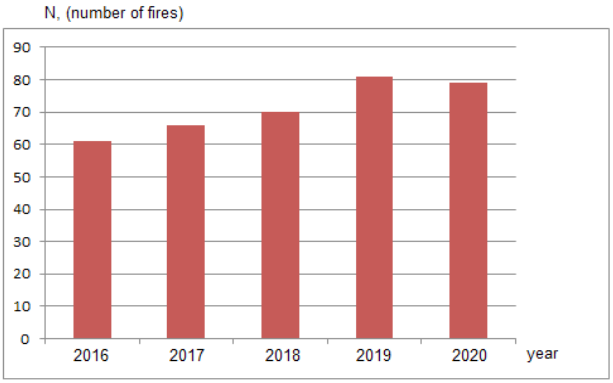


Figure 1 - Distribution of the territory of the Exclusion Zone

Recently, forest and peat fires have caused the greatest fire hazard in the Exclusion Zone, especially in the warm season. The area of coniferous forests is 150 thousand hectares, peat bogs - 7 thousand hectares.

Data on fires on the territory of the Exclusion Zone are presented in the form of a histogram (Figure 2)



Note. The histogram takes into account the fires, which took into account 11 SFRD and SSE "Northern Forest" ("Severnaya Pushcha"). This does not take into account minor fires.

Figure 2 - Fluctuations in the number of fires over the past 5 years

The technogenic hazard of the territory of the Exclusion Zone is based on the Chernobyl nuclear power plant with the presence of radioactive substances (power units No. 1 - 3), the Shelter object and the Vector production complex, which includes: storage facilities for solid radioactive waste SRW - 1, SRW - 2; building for preparation of containers for burial; specially equipped near-surface storage facilities for solid radioactive waste; drainage gallery with transformer substation; storage area for operational equipment (for 50 units); drainage pumping station, centralized storage for long-term storage of spent sources of ionizing radiation.

In the city of Chernobyl, the basis of the fire hazard is a gas station and a building of boxes for buses.

Fire protection of the territory of the Exclusion Zone is provided by two state fire and rescue units located at the Chernobyl NPP and in the city of Chernobyl (part of the 11 State Fire and Rescue Detachment), as well as units of the departmental fire protection of the State Agency for Management of the Exclusion Zone (hereinafter - SMEZ). The number of available fire brigades is shown in Table 1.

Table 1 - The composition of the existing state fire and rescue units

2 SFRD			11 SFRD		
Index	Number of personnel by state	Number of fire and rescue vehicles	Index	Number of personnel	Number of fire and rescue vehicles
	116	12		121	13
Guard:	25	5	Guard:	27	7
Reserve:	-	7	Reserve:	27	6

In addition, the fire safety of the forests of the Exclusion Zone is carried out by the departmental fire brigade of SMEZ. The structure of which includes 4 forest fire stations of the state specialized enterprise "Severnaya Pushcha", their number is 96 people (48 people on shift duty) and 50 units of equipment (35 units in operational calculation).

2.2. Fire department call analysis.

Based on the analysis of the data of the logbook of the fire brigade communication center on the time of involvement of fire and rescue units to extinguish fires on the territory of the Exclusion Zone, the distribution of calls by service time for the last five years was carried out. Calls were distributed at regular intervals. By the formula (1) the relative frequency of calls is determined.

$$W(A) = \frac{m}{n}, \quad (1)$$

where m - the number of calls in a given period;

n - total number of calls

The results of the distribution of calls of fire departments by service time are summarized in table 2.

Table 2 - Distribution of calls by time periods

Time interval τ, hour.	0 – 1	1 – 2	2 – 3	3 – 4	4 – 5	5 – 6	6 - 7	7 – 8 >
Empirical frequency (number of calls)	14	25	17	13	7	10	14	25
Relative frequency	0,12	0,21	0,14	0,10	0,05	0,08	0,11	0,21

Based on Table 2, we obtain a graph of distribution of calls by service time (Figure 3).

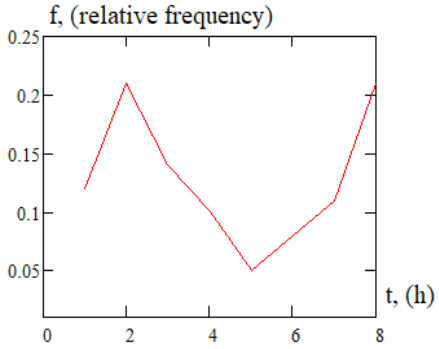


Figure 3 - Distribution of calls by service time

The graph in Figure 3 shows that the largest number of calls served by fire and rescue units falls on the period from 1 to 2 hours, and the smallest from - from 5 to 6 hours. At the same time, there is a tendency to increase the service time of one call in the period from 7 to 8 hours. This is due to the extinguishing of prolonged forest fires, which involve fire and rescue units to assist forestry.

The average service time of one call $\tau_{service}$ is determined on the basis of data observed in the Exclusion Zone by formula (2):

$$\tau_{service} = \sum_{k=1}^{n}(m_k\,(\frac{\tau_k + \tau_{k+1}}{2}))/\sum_{k=1}^{n} m_k \quad (2)$$

where m_k – the number of calls in a given time interval;

τ_k – the lower limit of the interval;

τ_{k+1} - the upper limit of the interval (it is the lower for the next interval);

n – number of intervals.

Calculate the average service time by formula (2):

$\tau_{servi\,ce}$ = 3,98 hours ≈ 4 hours

Based on the analysis of the departures of state fire and rescue units and fire and rescue units of the departmental fire brigades SMEZ in 2020, data were obtained on the frequency of use of fire and rescue vehicles when extinguishing one fire in the Exclusion Zone. At the same time, the involvement of aircraft, forces and means from other garrisons was neglected to extinguish these fires. A total of 79 fires were responded to. The frequency of use of fire and rescue vehicles is determined on the basis of data obtained from the analysis of the discrete variation series of table 3 by formula (3):

$$a_k = m_k \,/ \sum_{k=1}^{n} m_k, \quad (3)$$

where m_k – the number of calls serviced by a fire and rescue vehicle

Table 3 - Data of a discrete variation series

Number of vehicles, k	1	2	3	4-7	8-22	≥23
Number of calls serviced by the vehicle, m_k	12	21	13	26	7	0
Frequency of vehicle use, a_k	0,15	0,26	0,16	0,33	0,08	0

Construct a polygon of empirical distribution (Figure 4).

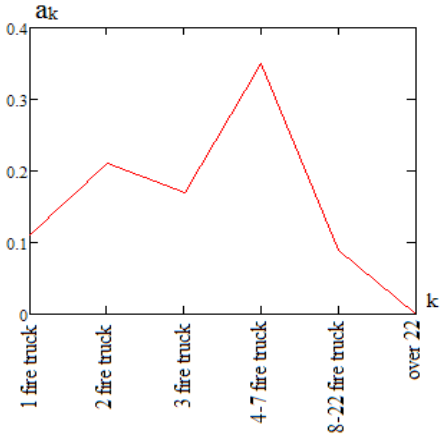


Figure 4 - Distribution of fire and rescue vehicles

The calculations show that 4 to 7 fire and rescue vehicles are most often used at the same time, but in some cases it is possible to use up to 22 units of basic equipment. Based on these data, fire and rescue units should be provided with such a number of fire trucks and other firefighting equipment that under any circumstances it will be able to respond effectively to the threats and dangers that exist in the Exclusion Zone.

Results. 3.1. Forecasting method for fire development.

An important tool for the development of the fire situation in the future is a forecasting method that uses both past experience and current assumptions about the future.

Analysis of the values of the presented data on the number of fires shows that they have a dependence close to linear. Therefore, as a trend we can choose a linear function:

$$y = ax + b, \quad (4)$$

where a and b – coefficients determined by the method of least squares.

The coefficients a i b of the system of normal equations are found by the formulas:

$$\text{à} = \frac{n\sum_{i=1}^{n} N_i t_i - \sum_{i=1}^{n} t_i \sum_{i=1}^{n} N_i}{n\sum_{i=1}^{n} t_i^2 - (\sum_{n=1}^{n} t_i)^2} \quad b = \frac{\sum_{i=1}^{n} N_i \sum_{i=1}^{n} t_i^2 - \sum_{i=1}^{n} t_i \sum_{i=1}^{n} N_i t_i}{n\sum_{i=1}^{n} t_i^2 - (\sum_{n=1}^{n} t_i)^2} \quad (5)$$

We perform the calculation using normal equations (5) for the linear dependence. To calculate the parameters of the function, we make a calculation table 4.

Table 4 - Calculation table of the least squares method

Year	Number of fires, N_i	Time, t_i	$N_i t_i$	t_i^2
2016	61	2016	122976	4064256
2017	66	2017	133122	4068289
2018	70	2018	141260	4072324
2019	81	2019	163539	4076361
2020	79	2020	159580	4080400

From formula (5) based on the data in table 4 we obtain the values of the coefficients *a* and *b* are 0.2 and 289, respectively.

Hence the equation of functional dependence will be:

$$N_i = -289 + 0.2t_i \quad (6)$$

According to the formula (6) we can develop the forecast of quantity of fires for the next year:

$$N_i \approx 115$$

Thus, the number of fires in the Exclusion Zone is expected to increase next year (Figure 5). However, this forecast does not take into account weather conditions, which significantly affect the number of fires, especially in summer. This is quite significant, as the vast majority of recorded fires in the statistics for 2016-2020 are grass fires. However, it is worth noting that the number of fires 115, although conditional, confirms the trend towards increasing the number of fires.

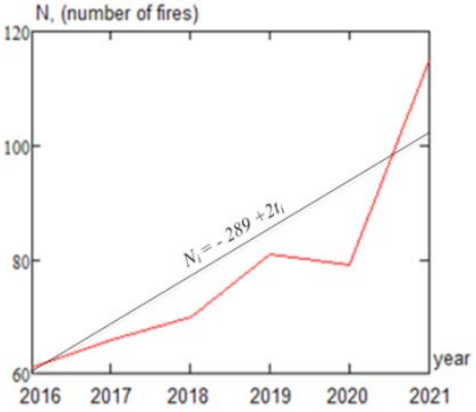


Figure 5 - The trend of changes in the number of fires in the Exclusion Zone

3.2. Assessment of the location of existing fire departments in the Exclusion Zone

The analysis of the locations of fire and rescue units showed that there are 2 state fire and rescue units and 4 forest fire stations on the territory of the Exclusion Zone (Figure 6).

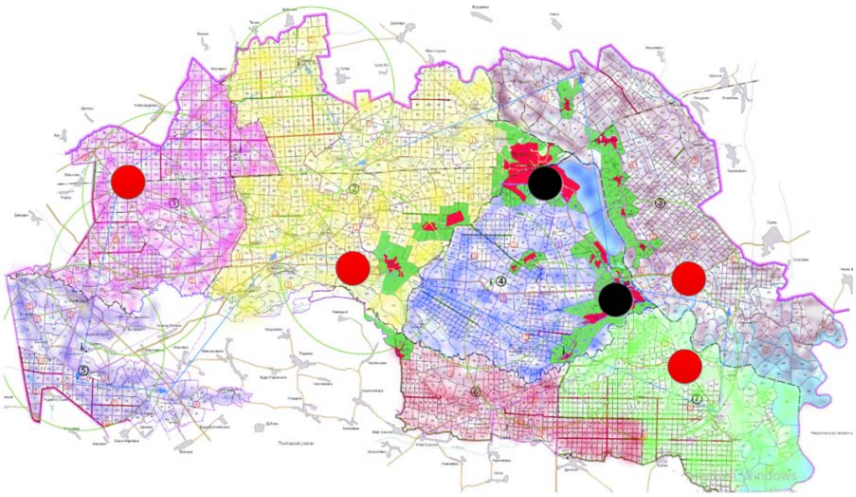


Figure 6 - Locations of fire and rescue units in the Exclusion Zone: black circle - state fire and rescue unit, red circle - forest fire station

Figure 6 shows that the location of fire departments on the territory of the Exclusion Zone is uneven, which jeopardizes fire safety.

An assessment of the location of existing fire departments in the Exclusion Zone, taking into account the standard time of arrival at the fire 20 minutes in accordance with the requirements [2] showed that existing fire departments can ensure proper fire response only in one third of the Exclusion Zone.

In this regard, the method of expert assessments, taking into account the defined criteria, decided to form additional 8 fire and rescue units, of which 7 forest posts and 1 departmental fire and rescue unit SMEZ on complex of productions “Vector”. Determination of the location of additional units was made on the basis of the following criteria:

- threats and dangers posed by local areas;
- estimated fire forecast for the next year;
- availability of roads;
- uniformity of distribution on the territory;
- the criterion of time in 20 minutes, which outlines the service areas of these units.

On the basis of the above defined criteria, the modeling of service areas of existing and additionally necessary fire and rescue units was carried out for an appropriate response to fires in the territory of the Exclusion Zone. The simulation results are plotted on a map (Figure 7).

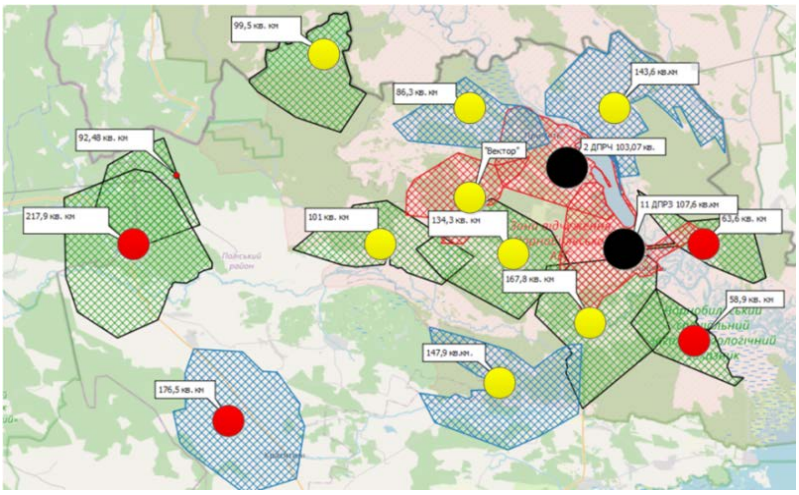


Figure 7 - Locations with service areas of fire and rescue units: black circle - state fire and rescue unit, red circle - forest fire station, yellow circle - additional necessary fire and rescue units

Discussion/Conclusions. 1. On the basis of processing of threats and dangers of the territory of the Exclusion Zone, fire and man-caused danger is determined. Analysis of fire statistics showed that the number of fires is growing every year, the tendency to change their number has a dependence close to linear.

2. The calculation of the distribution of calls by service time showed that fire and rescue units are most involved in the time intervals from 1 to 2 hours and from 7 to 8 hours. And the average service time of one call is about 4 hours. This must be taken into account when calculating the number of fire and rescue units. Because the work of units is carried out in conditions of radiation contamination of the territory, which in turn requires the rotation of personnel.

3. On the basis of the data of the discrete variation series the polygon of empirical distribution of fire and rescue vehicles is constructed. It is established that from 4 to 7 fire-rescue vehicles with a frequency of a_k = 0.33 vehicles are most often used at the same time. At the same time, with a frequency of a_k = 0.08, the use of 8 to 22 units of the main firefighting equipment is observed.

4. Based on the data of the calculation table of the least squares method, the equation of functional dependence of the forecast calculation of the number of fires for the next year in the Exclusion Zone was obtained for the first time and the tendency to increase the number of fires was confirmed.

5. It has been established that the existing fire and rescue units of the Exclusion Zone ensure a proper response to fires only in one third of the territory. In this regard, on the basis of certain criteria, mathematical modeling of the necessary fire and rescue units was carried out. It has been established that in order to properly respond to fires, it is necessary to provide an additional 7 forest fire stations and 1 departmental fire and rescue unit of SMEZ on complex of productions “Vector”.

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ЧЕРНОБЫЛЬ АПАТЫНЫҢ САЛДАРЫНАН ЛАСТАНҒАН АУДАНДАРДАҒЫ ӨРТТЕРГЕ ДЕН ҚОЮ ЖҮЙЕСІН ЖЕТІЛДІРУ

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СОВЕРШЕНСТВОВАНИЕ СИСТЕМЫ РЕАГИРОВАНИЯ НА ПОЖАРЫ НА ТЕРРИТОРИЯХ, ПОДВЕРГШИХСЯ РАДИОАКТИВНОМУ ЗАГРЯЗНЕНИЮ ВСЛЕДСТВИЕ ЧЕРНОБЫЛЬСКОЙ КАТАСТРОФЫ

Аннотация. На основе анализа статистических данных о пожарах территории Зоны отчуждения установлена растущая тенденция их количества, которая имеет зависимость, приближенную к линейной. Установлена пожарная и техногенная опасность территории Зоны отчуждения, а также имеющиеся пожарно-спасательные подразделения. Проведен расчет распределения вызовов по времени обслуживания и установлено, что пожарно-спасательные подразделения больше задействованы на временных промежутках от 1 до 2 часов и от 7 до 8 часов, при этом среднее время обслуживания одного вызова составляет около 4 часов. На основе данных расчетной таблицы метода наименьших квадратов впервые получено уравнение функциональной зависимости прогнозного расчета количества пожаров на следующий год на территории Зоны отчуждения и подтверждена тенденция к росту числа пожаров. Установлено, что имеющиеся пожарно-спасательные подразделения Зоны отчуждения обеспечивают надлежащее реагирование на пожаре лишь на трети территории. В связи с этим предложены дополнительные пожарно-спасательные подразделения с нанесением зон обслуживания на карту по определенным критериям.

Ключевые слова: Зона отчуждения, реагирование на пожары, время обслуживания одного вызова, пожарно-спасательное подразделение, место дислокации.

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