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DETERMINATION OF WAYS OF PROTECTING CRITICAL OBJECTS OF THE ENERGY COMPLEX AGAINST AIR STRIKES THROUGH THE JOINT APPLICATION OF DIFFERENT FORCES AND MEANS

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Abstract. *The experience of the Russian-Ukrainian war in 2022 once again confirmed to the whole world that for terrorist organizations and terrorist countries, which are unable to achieve victory on the battlefield, the main thing is to strike critical objects of the state's infrastructure: the energy complex, bridges, etc.*

In this context, the task of ensuring comprehensive protection of critical state infrastructure objects from air strikes is urgent.

The study of the subject area of compatibility and the combined use of means of physical influence (MPI) and means of radio-electronic influence (REI) theoretically assumes the presence of abstract objects with their connections and interconnections, which are created for the purpose of an idealized description and study of possible situations and order of actions for them.

This work examines the issue of increasing the effectiveness of protecting critical facilities of the energy complex (CFEC) from air strikes due to the combined use of anti-aircraft fire and anti-aircraft fire protection, methods of determining the locations of physical impact means, which allows to evaluate the expected results of combined actions, as well as to develop scientifically based recommendations for their effective combined use, which is news.

Means of physical influence may include firearms that are in service in the armed forces and other law enforcement agencies, interceptor drones, rifles with nets and other means.

Means of radio-electronic influence may include means of radio-electronic warfare, electromagnetic guns and other means based on fundamentally new physical principles of operation.

Keywords: *critical objects of the state's energy complex, compatibility, means of physical influence, means of radio-electronic influence, means of air attack.*

I. INTRODUCTION

In the world, a significant number of dangerous critical objects are located on the territory of most states. The degree of danger of the object is established based on the share of the civilian population and the territory that fall into the zone of possible neutralization in the event of an accident at a dangerous object. The results of terrorist acts during 2019-2022 in the world and the course of the Russian-Ukrainian war show that the most dangerous objects today are the objects of the energy complex.

One of the most famous examples of the use of drones to attack land and sea targets was the events in the Persian Gulf. On September 14, 2019, the Yemeni Houthis attacked Saudi Aramco's oil facilities in Abqaiq and Khurais (Saudi Arabia) with the help of UAVs, which are at a distance of at least 900 km from Yemen. The result of the attack was causing quite significant financial losses to oil companies.

In just nine months of 2022, more than 184 cruise missiles and more than 95 unmanned aerial vehicles, including more than 70 Iranian Shahed-136 kamikaze drones, were fired at Ukrainian cities where critical facilities of the state's energy complex were located. According to the calculations of the world's leading economists, the economic damage caused by these strikes to the state amounts to more than 300 billion dollars.

It is because of this that it is necessary to define measures and develop certain methods to protect the CFEC from air strikes. Ukraine has sufficient experience in the organization of air defense of troops and certain important objects, including nuclear energy objects, against conventional means of defeating air bases. At the same time, the development of unmanned aviation and, first of all, kamikaze drones [1, 2] opened up new opportunities for the use of air attack means (AAM) in relation to critical objects, including critical objects of the energy complex.

The leading countries of the world have focused their efforts in the protection of critical objects on a combination of the use of physical and electronic means of influence, which is new for the defense forces of Ukraine and involves studying the issue of the compatibility of the means of physical influence and means of radio-electronic influence available in our country to protect CFEC from actions of AAM. The study of these issues will allow to assess the expected effectiveness of joint actions, as well as to develop scientifically based recommendations for their application.

II. LITERATURE ANALYSIS

In solving the problem of protecting critical objects of the energy complex from air strikes, three directions can be distinguished:

1. Determination of the list of critical objects of the energy complex of the state that require protection from air strikes.

2. Determining the composition of the forces and means that must be involved to protect the CFEC from air strikes.

3. Deployment of specified forces and means to protect selected critical facilities of the energy complex. Evaluating the effectiveness of the combined use of various forces and means.

Legislative initiatives and scientific works, which were reflected in the publications of specialists in this area, are devoted to these issues.

The Law of Ukraine "On Critical Infrastructure" 1882-IX dated 16.11.2022 and Resolution of the Cabinet of Ministers of Ukraine dated 09.10.20 No. 1109 "Some Issues of Critical Infrastructure Objects" define the concept of critical infrastructure, the procedure for ensuring its functioning, and a list of these objects. The relevant directive documents of the defense forces of Ukraine determined the composition of the forces and means involved in the protection of specified objects and in the vast majority of these means of protection were stationary anti-aircraft missile complexes of the Air Force of Ukraine. At the same time, the experience of Russian terrorist attacks from the air on the objects of the energy complex of the state proved that in order to ensure the vital activity of the state, the list of objects that are subject to protection from air strikes should be expanded, and accordingly, it is necessary to involve additional means for protection, which do not belong to the anti-aircraft missile system of the Air Force of Ukraine.

A number of scientific works have been published, dedicated to solving the tasks of joint performance of the tasks of air defense means and means of radio-electronic warfare, for example [3-5], in which the main principles and approaches to determining the possibility of their joint application are formulated, and various options for building air defense units in the area are proposed.

The question of protection of explosive objects was studied in the scientific works of A. Volkov [6] and O. Lezik [7, 8], the question of determining the effectiveness of the use of air defense units and recommendations for their use were considered in the works of M. Yermoshin [9], V. Horodnova [10].

At the same time, the analysis of scientific works shows that they primarily considered the issues of protecting military facilities, such as ammunition depots, the accumulation of equipment from strikes by conventional air-based weapons, a number of problematic issues require further study, there is a need to improve methodological approaches to determining the rational placement of protection means around the protected object, making recommendations and evaluating the effectiveness of the created protection. Therefore, the goal of further research may be to consider the effectiveness of the combined use of physical and electronic means of influence to protect critical facilities of the state's energy complex.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The object of the study is the system of protection of critical facilities of the energy complex of the state.

The subject of the research is the combined use of means of physical influence and means of radio-electronic influence.

The purpose of the work is to evaluate the results of the combined actions of means of physical influence and means of radio-electronic influence during the protection of critical objects of the energy complex from air strikes.

Objectives of the study:

1) analysis of the compatibility of means of physical influence and means of radio-electronic influence;

2) development of a methodology for choosing the place of placement of means of physical influence during the protection of CFEC from air strikes;

3) development of scientifically based recommendations for the effective combined use of means of physical influence and means of radio-electronic influence and their coordination.

Research methods – system analysis, development of methods for choosing the place of placement of means of physical influence, mathematical modeling.

IV. RESULTS

4.1. Determination of the method of choosing the place of placement of means of physical influence during the protection of critical objects of the energy complex from air strikes.

In order to develop a method for choosing the place of placement of MPI during the protection of CFEC from an air strike, it is proposed to use an algorithm (Fig. 1), which consists of procedures and tasks that are performed sequentially, as a result of which proposals are formed for the selection of places of placement of MPI, their number and evaluation results.

The initial data for calculating the distance between the MPI (block 1) are:

– types of AAM that can be applied to the object of protection;
– geographic coordinates of the object of protection and their spatial dimensions;
– the composition of MPI allocated for the protection of the object;
– the maximum efficiency of the use of MPI;
– characteristics that describe the effectiveness of the use of MPI.

The initial data are selected from prepared databases, which are formed in advance or during the preparation of the solution (block 1).

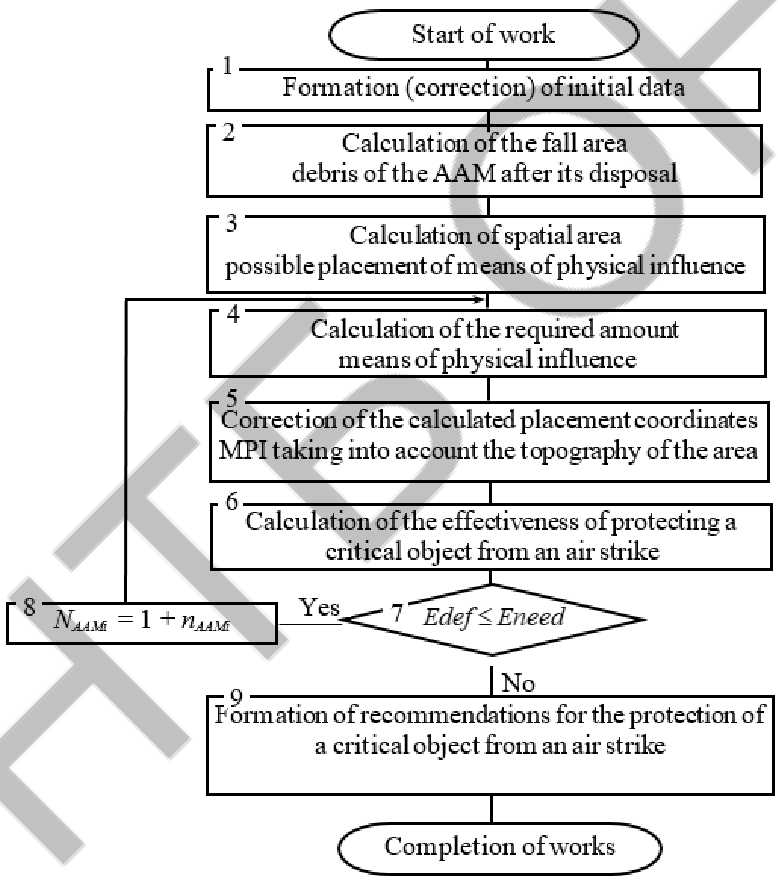

Figure 1. Algorithm for choosing the location of the anti-aircraft missile system during the protection of the object from an air strike

In block 2, the area of fall of the AAM debris after its neutralization is calculated. To perform this task, an existing model [11] is used. The calculation of the area of fall of AAM fragments is carried out in order to determine the required distance of placement locations from the perimeter of the protection object. The analysis of the results of the simulation of the neutralization of the AAM at all possible flight speeds and altitudes showed that the removal distance of the locations should lie within 1 to 2 km from the protection object.

Among the boundaries that determine the operation of the MPI, the most important place is the range of the AAM from the object of protection, at which the task of its neutralization should be set. This range depends on which means of physical influence the task is set, on the flight height of the AAM and the time of work on detecting and neutralizing the AAM, on the distance of the removal of the neutralization zone beyond the protection object.

The horizontal distance from the object of protection to the boundaries of setting the tasks for the disposal of the AAM is determined by the formulas:

$$d_{\mathrm{d.s.t}} = d_{\mathrm{d.MPI}} + V_{\mathrm{AAM}} \left(t_{\mathrm{d.p.MPI}} + t_{\mathrm{t.n}} \right), \qquad (1)$$

where $d_{\mathrm{d.s.t}}$ – the horizontal distance from the object of protection to the boundary of setting tasks;

$d_{\mathrm{d.MPI}}$ – distance of the MPI location from the protection object;

V_{AAM} – air attack vehicle speed;

$t_{\mathrm{d.p.MPI}}$ – the time of direct preparation of the MPI to neutralize the means of air attack;

$t_{\mathrm{t.n}}$ – time for neutralization of the means of air attack at the border of the zone of neutralization.

In block 3, the calculation of the spatial zone of the possible placement of means of physical influence is carried out. Fragments of the EC should not fall on the object of protection, therefore the disposal of the EC should be carried out on average (depending on the type of EC) at a distance of 2 km or more from the object of protection. Proceeding from this place of placement of anti-aircraft guns, they must move beyond the territory of the protection object at a distance of 1 km or more. The greater the distance of the location of the MPI, the greater the probability of preserving the object of protection. On the other hand, the greater the distance of the location of the MPI from the object of protection, the more means must be involved for its reliable protection. In practice, the number of means that can perform tasks is limited [10]. Therefore, it is necessary to place the locations of means of physical influence as close as possible to the object of protection, guided by their characteristics and the number of MPI allocated for the protection of the object.

After obtaining the value of the required distance of the location of the anti-aircraft fire protection system beyond the protection object, the required number of anti-aircraft fire protection devices is calculated (block 4).

The next step is the implementation of the algorithm for correcting the calculated coordinates of the location of the MPI based on the analysis of the digital map of the area (block 5). If the terrain or the nature of the terrain creates obstacles for the placement of the MPI, then correction of their placement is carried out. A program for displaying the MPI in accordance with the proposed locations on the electronic map is being implemented [10].

For a more detailed and qualitative assessment of the location of the MPI in block 6, an algorithm for assessing the degree of protection of objects by means of physical impact was implemented. The assessment of the degree of protection of objects is performed in the form of a calculation table showing the coefficients of the overlap of the neutralization zones and the load coefficients of the MPI. Using this information (blocks 7-9), the final decision is made regarding the locations of the MPI.

With regard to the location of means of radio-electronic influence, it is appropriate to indicate the definition of such places where they can operate without interfering with the work of the MPI. This is, for example, taking into account the norms of frequency-territorial spread, the appropriate distance between MPI and REI when they work together.

4.2. Determination of the compatibility of the actions of means of physical influence and radio-electronic influence due to the analysis of their compatible actions.

In order to assess the impact of the compatibility of means of physical and radio-electronic influence on the effectiveness of their combined actions, it is necessary to consider the essence of the term "compatibility", as well as to logically connect the concepts and terms related to the concept of "compatibility of physical and radio-electronic influence".

At the same time, the terminological system and its elements-terms must have certain properties that are presented to it:

systemic conditioning of terms, their interdependence, subordination according to a certain feature;

unambiguity within military science and general science disciplines;

context-independent term clarity;

correlation of the term with only one concept;

the brevity of the term and the lexicographic approach to creating terms;

the ability of the terminology to expand, clarify and change, the possibility of the transition of the term to the designation of a generic concept.

Based on the listed requirements for terminology and the analysis of existing basic special terms, the "zone of combined actions of means of physical influence and means of radio-electronic influence" means the territory where they are located and the area of airspace where neutralization and radio-electronic suppression of air attack means is carried out.

Thus, the application of all possibilities related to the use of means in the zone of joint actions should be considered as a set of four constituent parts:

1. "Information interoperability of means of physical influence and radio-electronic influence" – as the ability to carry out coordinated simultaneous actions of these means in the zone of simultaneous duty.

2. "Compatibility with regard to the conditional neutralization of AAM by means of physical and radio-electronic influence" – as the ability to take coordinated actions on PPE in the zone of compatible actions of means of physical and radio-electronic influence.

3. “Electromagnetic compatibility of the effective use of means of physical influence and radio-electronic influence” – as the ability of radio-electronic means to simultaneously function in real operating conditions with the required quality under the influence of unintentional radio interference and not to create unacceptable radio interference to other means [13].

4. “Compatibility for effectively changing the location of means of physical and radio-electronic influence” – as the ability to simultaneously fold, move taking into account the possibility of the means and quickly deploy to a new location.

The evaluation of the effectiveness of the combined actions of MPI and REI is intended to solve the scientific task, achieve the goal of the research and includes:

– selection and justification of indicators of the effectiveness of the use of MPI and REI;

– research on the dependence of the effectiveness of the combined actions of MPI and REI on the formalized indicators of alternative options for the use of MPI.

4.3. Determining the effectiveness of protection of critical objects of the energy complex from air strikes due to the combined use of physical impact and radio-electronic impact means.

In general, the scientific task of researching the combined actions of means of physical and radio-electronic influence in the protection zone of the CFEC is multivariate. The number of options (n_{var}) depends on the number and types of these means and can be determined by the ratio:

$$n_{\text{var}} = \left(N_{\text{MPI}_i} + 1\right)\left(N_{\text{MPI}j} + 1\right)\left(N_{\text{n.r.s}} + 1\right)\left(N_{\text{r.r.s}} + 1\right)..., \tag{2}$$

where N_{MPI_i} – the number of means of physical influence of the *i* type;

$N_{\text{MPI}j}$ – the number of means of physical influence of the *j* type;

$N_{\text{n.r.s}}$ – the number of noisy radio interference stations;

$N_{\text{r.r.s}}$ – the number of pulse response radio interference stations.

The composition of means of physical influence and radio-electronic influence and the order of their placement are mutually determined and closely interdependent. This relationship is caused, on the one hand, by those methodological approaches that exist to justify the optimal quantitative composition due to the necessary order of their placement, on the other hand, by the fact that any composition of means must be placed relative to the object of protection in a rational way [9]. The effectiveness of joint actions depends both on the composition of the means and on the order of their placement, the parameters of which are the range of the places of placement of means of physical influence $(d_{\text{l.MPI}})$ and means of radio-electronic influence $(d_{\text{l.REI}})$ from the borders of the object of protection and mutual distances between the means protection $(D_{\text{MPI-REI}})$.

Thus, a rather complex nature of the dependence of the effectiveness of the MPI and REI actions is obtained, which can be represented in the form of a functional dependence:

$$E = f\{N_{MPI}\}\Big|_{N_{REI},\, d_{l.MPI},\, d_{l.REI},\, D_{MPI_i},\, D_{REI_i},\, D_{MPI\text{-}REI} = \text{const.}} \quad (3)$$

$$E = f\{N_{REI}\}\Big|_{N_{REI},\, d_{l.MPI},\, d_{l.REI},\, D_{MPI_i},\, D_{REI_i},\, D_{MPI\text{-}REI} = \text{const.}} \quad (4)$$

Places of placement of means are subject to the requirements of the task, i.e. places of placement of means of physical influence must be located at such a distance from the borders of the object of protection that ensures the removal of the neutralization zone of the means abroad from which it is possible to perform tasks of the AAM.

To assess the impact of the maximum effectiveness of the use of MPI and REI on the effectiveness of their combined actions, let's return to the essence of the term "compatibility".

The evaluation of the effectiveness of the combined actions of means of physical and radio-electronic influence during the protection of critical objects of the energy complex is intended to solve the scientific task, achieve the goal of the research and includes:

– selection and substantiation of indicators of effectiveness of combined actions of means of physical and radio-electronic influence;

– research on the dependence of the effectiveness of the combined actions of means of physical and radio-electronic influence on the formalized indicators of alternative options of different composition of these means.

The indicator of the quality of the result (effectiveness) of actions during the protection of critical objects of the energy complex is, in general, an m-dimensional vector that includes three groups of components: the achieved (expected) effect (g), time consumption (t) and resource consumption (c).

$$Y^m = \lfloor g^m, c^m, t^m \rfloor, \quad (5)$$

where Y^m – effectiveness of actions;

m – factors and conditions that determine the effectiveness of actions;

g^m – achieved (or expected) beneficial effect;

c^m – expenditure of resources;

t^m – waste of time.

The most adequate target for the purpose of means of physical impact during the protection of objects from air strikes is the indicator of the number of neutralized WPS from their total number that were involved in the strike. As for the selection of indicators of the ratio of opposing forces, the most complete confrontation of the MPI and AAM can reflect the ratio:

$$\sigma_i = \frac{\mathrm{K}_{\mathrm{MPI}_i\mathrm{neut\,max}}\left[1-\left(1-P_{\mathrm{prob.MPI}_i\mathrm{neut}}\right)^{n}\right]\mathrm{K}_{\mathrm{e.inf.prov}}\,N_{\mathrm{MPI}_i}}{D_{\mathrm{lim.par.MPI}_i\mathrm{zone}}\qquad N_{\mathrm{AAM}}} = \frac{\mathrm{K}_{\mathrm{MPI}_i\mathrm{c.p.}}\mathrm{K}_{\mathrm{e.inf.prov}}}{N_{\mathrm{AAM}}}, \quad (6)$$

where $\mathrm{K}_{\mathrm{MPI}_i\mathrm{neut\,max}}$ – the maximum number of MPIs of the *i* type that are simultaneously neutralized;

$P_{\mathrm{prob.MPI}_i\mathrm{neut}}$ – the probability of neutralization of MPI of the *i* type;

n – amount of spent resources;

$\mathrm{K}_{\mathrm{e.inf.prov}}$ – efficiency ratio of information provision;

N_{MPI_i} – the number of MPIs of the *i* type;

$D_{\mathrm{lim.par.MPI}_i\mathrm{zone}}$ – the limiting parameter of the MPI neutralization zone of the *i* type;

N_{AAM} – the number of military personnel involved in the attack on the object of protection;

$\mathrm{K}_{\mathrm{MPI}_i\mathrm{c.p}}$ – coefficient of MPI combat potential of the *i* type.

$$\mathrm{K}_{\mathrm{e.inf.prov}} = \frac{\mathrm{K}_{\mathrm{coef.f.p}}\mathrm{K}_{\mathrm{mask}}\left(1+N_{\Sigma_{\mathrm{t.p}}}\right)N_{\Sigma_{\mathrm{i.m}}}}{t_{\mathrm{s.MPI}}\left(1-t_{\mathrm{i.c}}\right)}, \quad (7)$$

where $\mathrm{K}_{\mathrm{coef.f.p}}$ – the similarity coefficient of false placements with true ones;

$\mathrm{K}_{\mathrm{mask}}$ – object masking factor;

$N_{\Sigma_{\mathrm{t.p}}}$ – the total number of forces and means of protection of the object of air strikes, which carry out disinformation measures;

$N_{\Sigma_{\mathrm{i.m}}}$ – the total number of information means in the composition of forces and means of protecting the object from air strikes, information flows participating in the collection process;

$t_{\mathrm{s.MPI}}$ – time of stay of the MPI at the place of placement;

$t_{\mathrm{i.c.}}$ – time of information collection.

Thus, the neutralization of AAMs during the protection of CFECs against air strikes is considered as a probabilistic process characterized primarily by the ratio of the forces of the parties.

In turn, to evaluate the effective use of means of radio-electronic influence to protect critical objects, the mathematical expectation of the number of AAM on which radio-electronic influence (suppression) of REI was carried out is used ($\mathrm{M}_{\mathrm{AAM\ sup.REI}}$).

$$\mathrm{M}_{\mathrm{AAM\ sup.REI}} = N_{\mathrm{AAM.\ sup}}\,\Delta P_{\mathrm{i.p}}, \quad (8)$$

where $N_{\text{AAM. sup}}$ – the number of AAM that were subjected to radio-electronic influence (suppression);

$\Delta P_{\text{i.p}}$ – the increase in the probability of saving the object, which is equal to the probability of conditionally neutralization of the AAM, which is determined depending on the number of conditionally neutralized AAM and is calculated according to the following formula:

$$\Delta P_{\text{i.p}} = P^{\text{p}}_{\text{p.rei}} - P^{\text{o}}_{\text{p.a.rei}}, \tag{9}$$

where $P^{\text{p}}_{\text{p.rei}}$ – the probability of preserving the object of protection in the conditions of countering the means of radio-electronic influence (obstructing them);

$P^{\text{o}}_{\text{p.a.rei}}$ – the probability of preserving the object of protection in the absence of countermeasures against means of radio-electronic influence.

For the case of protecting the object only the expression (9) can be transformed into the form:

$$P_{\text{REI}} = 1 - e^{-N_{\text{REI}}\,\Delta P_{\text{p.s.REI}} / N_{\text{AAM}}}, \tag{10}$$

where $P_{\text{p.s.REI}}$ – the probability of saving a critical object is only REI;

N_{REI} – number of REI;

N_{AAM} – number of AAM.

The analysis of ratios shows that when evaluating the effectiveness of actions, only the capabilities of the MPI or the capabilities of the radio-electronic influence of the REI with a fixed number of AAM participating in the strike on the object of protection are taken into account [7].

Therefore, as a result of the above-mentioned shortcoming, for conducting research it is proposed to convert the dependence into a form that allows determining the efficiency indicator of compatible actions:

$$P_i = 1 - e^{-\left(\frac{M_{\text{m.e.dest. MPI}}}{N_{\text{AAM}}} + K_{\text{comp.}}\frac{M_{\text{m.e.dest.REI}}}{N_{\text{AAM}}} + K_{\text{o.r.}}\frac{M_{\text{m.e.dest.low.alt}}}{N_{\text{AAM}}}\right)}, \tag{11}$$

where $M_{\text{m.e.dest. MPI}}$ – mathematical expectation of the number of destroyed AAM by MPI;

K_{comp} – compatibility coefficient of MPI and REI;

$M_{\text{m.e.dest.REI}}$ – mathematical expectation of the number of destroyed AAM by REI;

$K_{\text{o.r}}$ – coefficient of opportunity realization;

$M_{\text{m.e.dest.low.alt}}$ – mathematical expectation of the number of destroyed AAM at low altitudes.

Therefore, it can be concluded that for the evaluation of the effectiveness of the combined actions of MPI and REI, a generalized indicator was chosen in the form of a mathematical expectation of the number of AAM who did not complete the task, defined in relative value (P_i) and calculated according to formula (11). Based on the value of this indicator, it is possible to evaluate the expected results of the actions of the MPI and REI, the level of losses of the AAM and the extent to which they fulfill their task of damaging a critical object of the energy complex.

For the placement of means of physical influence on the site, a methodical technique was used for the directed selection of possible variants of the composition of the means within the framework of the existing structure, with the conditional placement of MPI at fixed distances (J) between the means $(\mathrm{MPI}-\mathrm{REI})$ relative to the object of protection.

To implement this technique, we will use the ratio:

$$D_{\mathrm{MPI-REI\ min}} = \mathrm{a} \cdot J \tag{12}$$

where $D_{\mathrm{MPI-REI\ min}}$ – the minimum range of MPI and REI from the center of the object of protection, at which their given number is evenly spaced at J intervals;

a – uniformity factor.

For MPI and REI relative to each other and the object of protection, we use the ratio:

$$D_{\mathrm{MPI-REI\ min}} = D_{\mathrm{det}} \le 0{,}65 D_{\mathrm{r.a}}\ , \tag{13}$$

where D_{det} – detection range;

$D_{\mathrm{r.a}}$ – the minimum range of ammunition.

$$D_{\mathrm{r.a}} = V_{\mathrm{AAM}}\ T_{\mathrm{am.d.AAM\ min}} - \Delta + V_{\mathrm{AAM}}\ T_{\mathrm{AAM\ dest}}, \tag{14}$$

where V_{AAM} – speed AAM, km/min;

$T_{\mathrm{am.d.AAM\ min}}$ – time of ammunition drop using AAM, min;

Δ – lag of weapons (ammunition) using AAM, km;

$T_{\mathrm{AAM\ dest}}$ – time of AAM destruction.

In order for the object to be protected by means of radio-electronic influence, it is necessary to place REI at a distance D_{REI}, which should be less than $D_{\mathrm{MPI-REI\ min}}$ and, in the best case, be equal to zero.

However, the reduction of the displacement of REI locations (D_{REI}) is limited by the possibility of destroying the object of protection when using weapons that are self-guided by REI radiation. The condition that determines the minimum and at the same time optimal value of D_{REI} has the following form:

$$D_{\mathrm{REI}} \ge D_{\mathrm{r.d.am}} + d_{\mathrm{r.prot}} + 3\sigma_{\mathrm{a.s.error}}, \tag{15}$$

where $D_{\mathrm{r.d.am}}$ – radius of damage by ammunition to the object of protection;

$d_{\mathrm{r.prot}}$ – the radius of the protection object;

$\sigma_{\mathrm{a.s.error}}$ – average squared error of weapons with homing.

The task of calculating the distance between the locations of anti-aircraft missiles during the protection of the object from air strikes is solved by selecting the locations of anti-aircraft missiles in two stages.

At the first stage, proposals for the placement of means of physical influence are developed in accordance with the requirements of the governing documents and the practice of organizing the protection of critical objects without taking into account the topography of the area [9].

At the second stage, correction of the coordinates of the placement of means of physical influence is carried out, taking into account the relief and nature of the terrain, the location of local objects, which affect the effectiveness of the use of PFV for decontamination of hazardous waste, using the capabilities of digital maps of the area.

The conducted analysis showed that it is necessary to have pre-equipped places for placement of means of physical and radio-electronic influence along the entire zone (perimeter) that is intended for preservation, or in the most important directions.

In each specific case, these factors must be taken into account when building a system to protect objects from air strikes.

The developed proposals were elaborated in a comprehensive model for evaluating the effectiveness of actions of means of physical influence.

The simulation that was carried out made it possible to obtain estimates of the probability of preserving the object of protection in the event of air strikes for typical anti-aircraft missiles, which can be cruise missiles and UAVs at different heights (Fig. 2).

The following flight heights were selected and displayed on the histogram AAM:

1 – up to 100 m; 3 – 500 – 1 000 m;
2 – 100 –500 m; 4 – more 1 000 m.

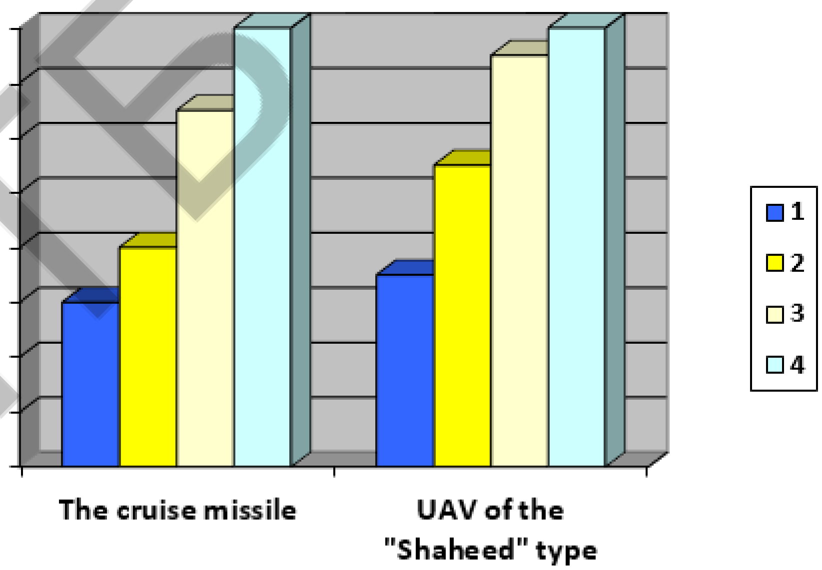

Figure 2. CFEC conservation probability plot

The analysis of the obtained results allows us to conclude that the application of the proposed proposals will allow saving the object of protection in case of air strikes with a probability of 0.7 to 0.8. Therefore, applying these proposals, it is possible to significantly ensure the protection of both the critical object of protection and the civilian population, as well as the territory from the possible consequences of damage to critical objects of the energy complex.

V. CONCLUSIONS

The list of critical objects of the energy complex for air strikes can be diverse and include important state objects that require reliable protection from air strikes.

According to the presented methodology, placement of means of physical and radio-electronic influence along the perimeter of the object of protection at specified distances allows, in case of neutralization of UAVs and cruise missiles, without causing them to fall into the territory of the CFEC.

The developed proposals for the use of means of physical influence to protect critical objects of the energy complex from air strikes in the integrated model for evaluating the effectiveness of the actions of the MPI allow us to state with confidence that the use of these proposals during the protection of the CFEC from air strikes will make it possible to ensure its security from with a probability ranging from 0.7 to 0.8. To evaluate the effectiveness of the combined actions of the MPI and REI means, a generalized indicator was chosen in the form of a mathematical expectation of the number of AAM that did not complete the combat task, defined in the relative value (P_i). Based on the value of this indicator, it is possible to evaluate the expected results of the actions of the MPI and REI means, the level of losses of the AAM and the degree of their fulfillment of tasks.

Studies show the expediency of taking measures to increase the effectiveness of the protection of the state's CFEC against air strikes due to the joint use of various forces and means, which is due to the need to ensure the vital activity of the state, the preservation of the ecological situation of the region where this or that critical object is located due to catastrophic consequences in the event its damage.

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