MODERN METHODS OF DISPOSAL OF LARGE-SCALE EMISSIONS OF DANGEROUS CHEMICAL AND RADIOACTIVE SUBSTANCES

СУЧАСНІ МЕТОДИ ОСАДЖЕННЯ ВЕЛИКОМАСШТАБНИХ ВИКИДІВ НЕБЕЗПЕЧНИХ ХІМІЧНИХ ТА РАДІОАКТИВНИХ РЕЧОВИН

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Abstract. The paper deals with the issues of liquidation of the consequences of emergencies related to emissions of hazardous chemical and radioactive substances into the atmosphere. Particular attention is paid to the method of artificially inducing precipitation as an effective way to clean the air. The structure of the contaminated area, the peculiarities of its spread and impact on the ecosystem, as well as the algorithm of actions for the organizational and technical implementation of this method are described. Different ways of delivering reagents to the clouds (drones, aircraft, missiles), characteristics of clouds suitable for precipitation, and factors that affect the efficiency of pollutant deposition are considered. The prospects of using electrophysical methods of air ionization to expand the meteorological conditions for the application of artificial precipitation are determined.

Keywords: artificial precipitation, air pollution, radioactive substances, chemical pollutants, deposition of harmful substances, meteorological conditions, emergencies, environmental safety.

Анотація. У роботі розглянуто питання ліквідації наслідків надзвичайних ситуацій, пов’язаних із викидами небезпечних хімічних та радіоактивних речовин в атмосферу. Особливу увагу приділено методу штучного викликання опадів як ефективному способу очищення повітря. Описано структуру забрудненої зони, особливості її розповсюдження та впливу на екосистему, а також алгоритм дій для організаційно-технічної реалізації цього методу. Розглянуто різні способи доставки реагентів у хмари (безпілотники, авіація, ракети), характеристики хмар, що придатні для опадів, та фактори, які впливають на ефективність осадження забруднювачів. Визначено перспективність використання електрофізичних методів іонізації повітря для розширення метеорологічних умов застосування штучного викликання опадів.

Ключові слова: штучне викликання опадів, забруднення атмосфери, радіоактивні речовини, хімічні забруднювачі, осадження шкідливих речовин, метеорологічні умови, надзвичайні ситуації, екологічна безпека.

INTRODUCTION

The problem of liquidation of the consequences of natural and man-made emergencies is an important state function, and its relevance is due to both the manifestations of natural disasters and the operation of a wide range of enterprises in the heavy, chemical and nuclear power industry.

Even under the conditions of normal operation of industrial enterprises, a large amount of dangerous chemicals are released into the environment. Especially large-scale emissions occur in the event of large-scale accidents at such facilities. After the start of active hostilities on the territory of Ukraine, the risks of hazardous chemical and radioactive substances being released into the atmosphere as a result of the destruction of chemical industry and nuclear energy facilities that came under missile attack increased significantly.

Figure 1. Consequences of rocket attacks on the Zaporizhzhya nuclear power plant and the Avdiiv coke-chemical plant[499,]

An additional factor of the danger of chemical and radiation contamination of a large area was the increased possibility of using chemical and atomic weapons of mass destruction. This poses a significant threat to the population, territory and environment. Obvious examples of the possible consequences of such accidents are the Chernobyl nuclear power plant accident and the Fukushima nuclear power plant accident.

METHODOLOGY

As a result of the accident at the Chernobyl nuclear power plant, the zone of radioactive contamination was more than 142,000 km^2 (Fig. 2, Table 1), and as a result of the accident in Fukushima, the zone of radioactive contamination was much smaller (~ 7,000 km^2) (Fig.3).

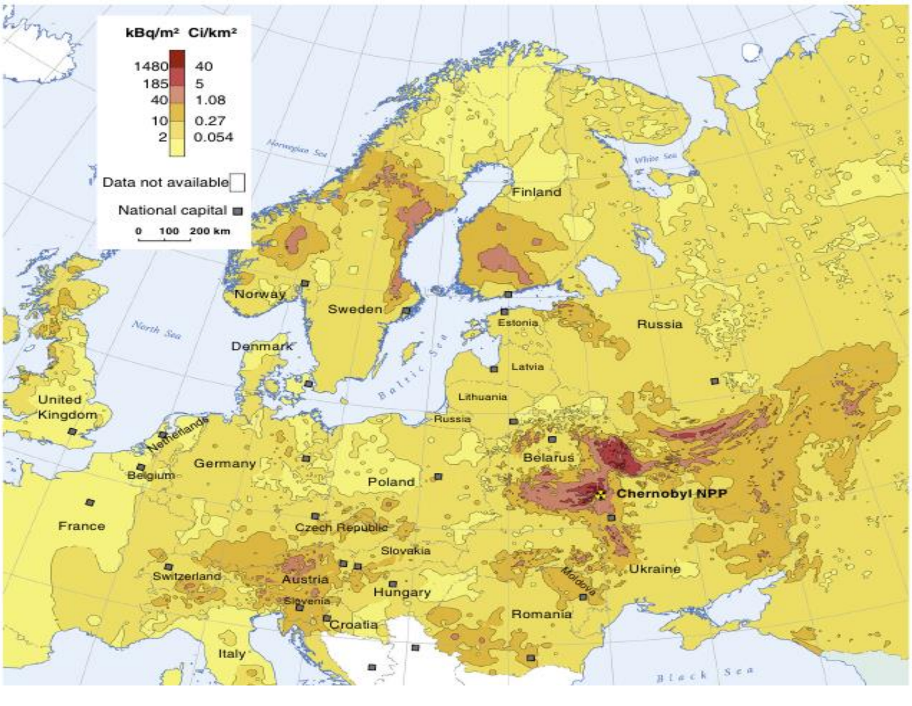

Figure 2. Surface pollution of ^{137}Cs in Europe after the accident at the Chernobyl nuclear power plant[500]

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[499] The International Atomic Energy Agency (IAEA) https://www.iaea.org/, [access date 12.05.2025]

[500] Georg Steinhauser, Alexander Brandl, Thomas E. Johnson (2014). Comparison of the Chernobyl and Fukushima nuclear accidents: A review of the environmental impacts. Science of The Total Environment. Volumes 470–471. Pages 800-817. https://doi.org/10.1016/j.scitotenv.2013.10.029

Table 1.

Radioactive contamination of the territory in European countries[2]

Country	**The area of the pollution zone (km^2)**			
	Zone 4 (37–185 kBq/m^2)	**Zone 3 (185–555 kBq/m^2)**	**Zone 2 (555–1480 kBq/m^2)**	**Zone 1 (> 1480 kBq/m^2)**
Russian Federation	49,800	5700	2100	300
Ukraine	37,200	3200	900	600
Belarus	29,900	10,200	4200	2200
Sweden	12,000			
Finland	11,500			
Austria	8600			
Norway	5200			
Bulgaria	4800			

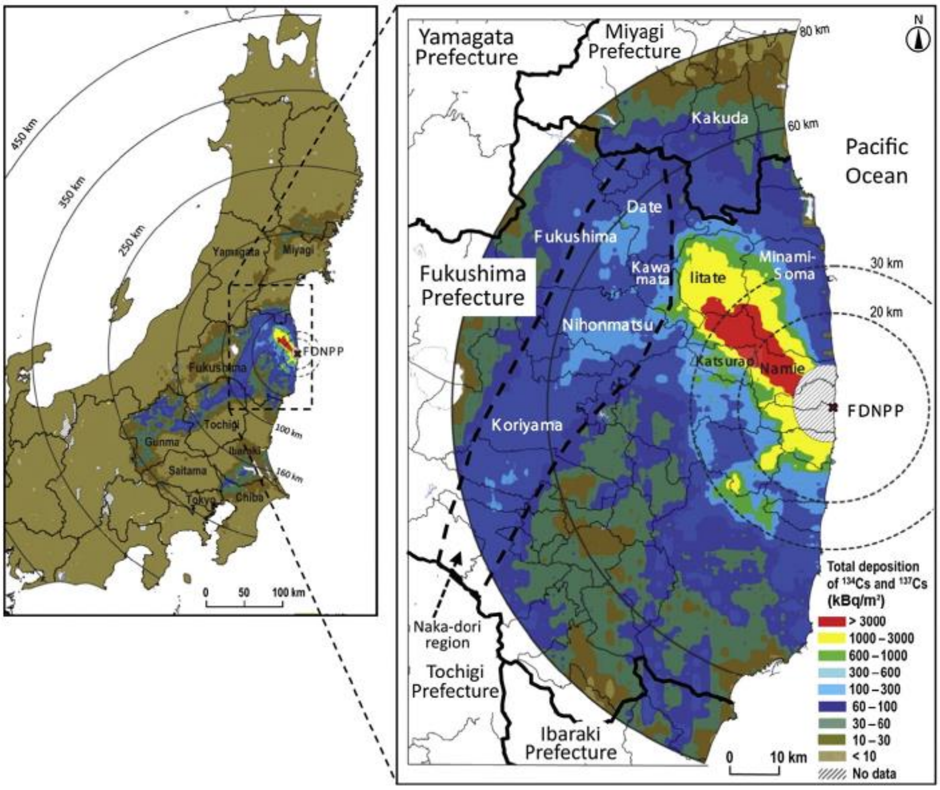

Figure 3. Estimated total fallout of radioisotopes after the nuclear accident in Fukushima, about half of which ^{137}Cs[2]

In fig. 2 and 3 present the contamination zones only for the ^{137}Cs isotope, but even these data show the larger size of the contamination zone and, accordingly, a large negative impact on the ecosystem of the region and the planet as a whole.

Due to the large scale of atmospheric pollution zones, which can extend to heights of up to several kilometers, the localization and elimination of the consequences of emergency situations causes significant difficulties and requires the involvement of a large number of forces and means. The existing methods and means of preventing emergency situations, which lead to the spread of dangerous substances in the atmospheric air, are based on the mechanisms of deposition of harmful substances by sprayed water, capable of affecting the affected area at heights of no more than ten meters. Therefore, almost the only method of air purification from combustion products is their washing out by atmospheric precipitation.

This method is based on the principles of sorption by falling drops of atmospheric precipitation of polluting chemical and radioactive substances in gaseous, liquid and solid aerosol states. At the same time, the lower part of the atmosphere, up to 5 km high, is divided into two conditional zones (Fig.4).

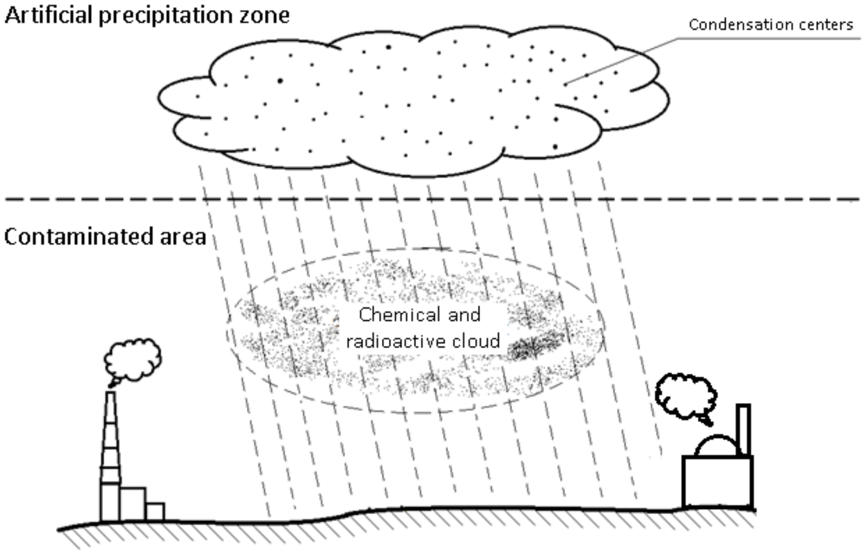

Figure 4. General scheme of the method of elimination of the consequences of emergency situations for atmospheric air by artificial initiation of precipitation

The contaminated zone directly refers to the zone affected by the atmospheric air from the emergency. The boundaries of the affected zone are determined by the limits of exceeding the maximum allowable concentrations for chemically dangerous substances and sanitary norms of the exposure dose for radioactive pollution.

Due to horizontal and vertical atmospheric flows, the contaminated zone spreads rapidly, which necessitates the prompt forecasting of the contaminated zone depending on the speed and direction of the wind. Clouds of chemical and radioactive materials and the territory of a natural fire can be located in the pollution zone as a powerful source of release of dangerous substances into the atmosphere. When flying through the contaminated zone, raindrops of varying intensity absorb hazardous substances, depositing them on the soil surface.

The second zone is the zone of artificial formation of precipitation from the lower to the upper border of clouds, potentially suitable for precipitation. Depending on the meteorological conditions, the height of the upper and lower limits of artificial precipitation zones may change. In this zone, the process of precipitation takes place directly, which is influenced by meteorological conditions (pressure, temperature, humidity, and cloud moisture, etc.) and the properties of natural or artificial nuclei of droplet formation (dispersity, concentration, electric charge, etc.). Potentially suitable for artificial influence are the clouds of the lower tier, among which the most water and moisture reserves are stratified rain (Nimbostratus Ns) and cumulus rain (Cumulonimbus Cb). Other types of clouds are capable of forming precipitation only after the phase of their transformation into Ns or Cb types.

However, the multifactorial nature of the parameters affecting the state of the atmosphere does not allow, using the methods and methods existing today, to successfully solve the task of forecasting the intensity of pollutant leaching from the atmosphere, choosing an effective method of artificial initiation of precipitation, and expanding the range of meteorological conditions that ensure a successful flow processes of artificial precipitation, etc.

RESULTS

The first real results regarding the artificial initiation of precipitation were obtained in the 20s of the 20th century. However, these works received the greatest development after the discovery in 1946 by the American scientist V. Schaefer of the properties of solid carbon dioxide and in 1951 by the Swedish scientist B. Vonnegut the properties of silver iodide as the most active centers of precipitation.

At the current stage, the most effective method of delivery and spraying of the active reagent is pyrotechnic charges. The study of the impact of the AgI reagent on the ecosystem was carried out by The Weather Modification Association (WMA). The results of these studies fully confirmed the safety of using the AgI reagent, which was officially registered in the report of the World Meteorological Association[501].

The methods of delivering the reagent to the affected area are different - this includes the use of specially equipped aircraft, unmanned aerial vehicles, and small-sized rockets (Fig. 5).

Figure 5. Methods of delivering the reagent to the clouds[502]

In the 1970s and 1980s, some countries tried to use military missiles such as GRAD/MLRS as missile carriers. At the same time, instead of a warhead, a reagent charge was placed in the rocket. This charge exploded at the appropriate height in the cloud, spraying the reagent. However, to date, this approach has shown its inefficiency. The main disadvantages are that it is economically impractical to use expensive military missiles with additional conversion. Also, the method of explosive spraying of the reagent at a certain point sows a small area. Today, small-sized special-purpose missiles have the advantage, which have proven themselves well in practice over the years. Polymers are used to manufacture the bodies of such missiles, which significantly reduces their weight and cost. Modern technologies of 3-D printing allow to additionally reduce costs and time for their production. An additional significant advantage of such rockets is the integration of the active reagent into the rocket's complex solid fuel. At the same time, the spread of the active reagent occurs during the flight of the rocket due to the burning of solid fuel. This allows to sow a significantly larger area of the cloud and obtain more dispersed particles of the reagent, which additionally increases the efficiency of raindrop formation.

AgJ is used as a crystal-forming reagent in precipitation practice. There is no single theoretical approach to explaining its high crystal-forming efficiency, but the main theoretical prerequisite for the

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[501] Weather Modification Association (2009). "Weather Modification Association Capability Statement." WMA URL: http://www.weathermodification.org/images/AGI_toxicity.pdf

[502] Yale School of the Environment *https://e360.yale.edu/features/can-cloud-seeding-help-quench-the-thirst-of-the-u.s.-west*, [access date 12.05.2025]

process of water crystallization on the surface of AgJ is the similarity of the structures of the crystal lattices of AgJ salt and ice crystals.

That is, from a physical point of view, the process of condensation of water vapor on a core with $r < r_{cr}$will occur, but the crystallization of condensed water does not occur. Therefore, at temperatures above -12 °C, the efficiency of using crystal-forming reagents, such as AgJ, decreases and the process of condensation of liquid water on the surface of the core begins to play a decisive role. In this case, an important property of precipitation reagents is their hygroscopicity.

Hygroscopicity refers to the ability of materials to absorb moisture from the air. The salts NaCl, $CaCl_2$and some acids are highly hygroscopic. The precipitation-forming activity of soluble hygroscopic materials can be estimated by the critical degree of supersaturation above which droplet formation can occur on the hygroscopic core, which is determined by Raoul's law.

The droplet-forming efficiency of hygroscopic condensation nuclei depends significantly on the concentration of the dissolved substance in the solution. Accordingly, with the growth of the droplet, the concentration of the nucleus dissolved in it decreases, which leads to a decrease in the efficiency of this condensation nucleus.

Precipitation over the affected area significantly accelerates the process of air purification. However, the intensity of the purification process can be increased by introducing special chemicals into the atmosphere that increase the intensity of sorption by raindrops or neutralize their negative impact. Since various toxic and radioactive substances differ significantly in their physical and chemical properties, chemical reagents can effectively affect only a certain class of pollutants with similar properties. The widest range of various hazardous substances is released into the atmosphere as a result of large natural and man-made fires. Therefore, in such cases, it is possible to use a combination of several reagents. Below are the modifiers of pyrotechnic compositions that increase the efficiency of cleaning the atmosphere from pollutants of various classes.

The qualitative and quantitative composition of combustion products significantly depends on the type of combustible substance and combustion conditions (temperature, oxidizer concentration), but their main components are CO_2, CO, NO, NO_2, SO_2, soot and ash[503]. Of this list, CO, NO, NO_2, and SO_2 have the greatest chemical activity. When they enter the atmosphere, these combustion products react with atmospheric gases. In the lower troposphere, in addition to H_2O, O_2 and inert CO_2 and N_2, there are highly active radicals - hydroxyl NO^-, hydroperoxide NO_2^- and nitrate ions NO_3^-. Such radicals appear in the atmosphere under the influence of ultraviolet radiation, and their concentration increases with altitude, but due to their high activity, they make a significant contribution to chemical processes in the lower troposphere. The chemically active components of combustion products react with radicals according to the following schemes:

$$\mathrm{CO} + \mathrm{HO}^{\bullet} \to \mathrm{CO}_2 + \mathrm{H}^{\bullet}; \tag{1}$$

$$\mathrm{CO} + \mathrm{HO}_{\dot{2}} \to \mathrm{CO}_2 + \mathrm{HO}^{\bullet}; \tag{2}$$

$$\mathrm{NO} + \mathrm{HO}^{\bullet} \to \mathrm{NO}_2 + \mathrm{H}^{\bullet}; \tag{3}$$

$$\mathrm{NO} + \mathrm{HO}_{\dot{2}} \to \mathrm{NO}_2 + \mathrm{HO}^{\bullet}; \tag{4}$$

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[503] Carslaw N., Jacoba P.J., Pilling M. J. Modeling OH, HO2,and RO2 radicals in the marine boundary layer 2. Mechanism reductionand uncertainty analysis. J. Geophys. Res. 1999. № 104. pp. 30257-30273.

$$NO_2 + HO^{\bullet} \rightleftarrows HNO_3; \tag{5}$$

$$NO_2 + NO_3^{-} \rightleftarrows N_2O_5; \tag{6}$$

$$N_2O_5 + H_2O \rightarrow 2HNO_3; \tag{7}$$

$$SO_2 + HO^{\bullet} \rightarrow HSO_3^{\bullet}; \tag{8}$$

$$HSO_3^{\bullet} + O_2 \rightarrow SO_3 + HO_2^{\bullet}; \tag{9}$$

$$SO_3 + H_2O \rightleftarrows H_2SO_4. \tag{10}$$

As can be seen from reactions (1) – (10), nitric and sulfuric acids are formed in the atmosphere as a result of chemical transformations of NO, NO_2, and SO_2. These acids are absorbed by water microdroplets. Under certain meteorological conditions, drops of water solutions of acids fall out, causing significant damage to crops and other vegetation.

On this basis, one of the methods of combating acid precipitation is the method of neutralizing acid before it hits the Earth's surface by spraying fine alkali. The introduction of finely dispersed alkali into the atmosphere can be carried out through the use of the pyrotechnic compositions discussed above.

The most commonly available alkalis are sodium and potassium hydroxides (NaOH, KOH). In addition, these alkalis are highly soluble in water, decomposing into ions, which leads to their high activity in neutralizing aqueous acid solutions.

Fine alkalis (NaOH, KOH) as fillers in the pyrochemical charge do not participate in the combustion process. As a result of the combustion of the pyrochemical charge, alkali particles are sprayed in contact with acidic atmospheric formations and neutralize them by reactions (11) – (14):

$$H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O; \tag{11}$$

$$H_2SO_4 + 2KOH \rightarrow K_2SO_4 + 2H_2O; \tag{12}$$

$$HNO_3 + NaOH \rightarrow NaNO_3 + H_2O; \tag{13}$$

$$HNO_3 + KOH \rightarrow KNO_3 + H_2O. \tag{14}$$

Since these alkalis have a rather low boiling point ($T_{(boil)}$ (NaOH) – 1676 K; $T_{(boil)}$ (KOH) – 1600 K), when the pyro-charge is burned, they sublimate, which leads to additional dispersion of alkali particles.

Naturally, the charge sign of the interacting particles will play a decisive role. If the interacting particles have different charges, the intensity of coagulation will increase; if the particles have the same charge, the opposite effect is observed.

The process of large droplets (Kn>0) capturing smaller ones can be referred to as gravitational coagulation. This mechanism is the main mechanism of droplet growth in the cloud in the period before rain.

The essence of the gravitational coagulation mechanism is the capture of small dispersed particles by a large raindrop when they fall. Small aerosol particles with radius r_p and concentration C_p float in the air under the influence of air currents ($V_{(0)} \approx 0$). Under the influence of gravity, precipitation droplets of size r_d move downward with a certain velocity V_d. When a large drop falls, it is surrounded by an air stream that carries small aerosol particles with it. However, since the aerosol particles have a mass other than zero, they are subject to inertial forces that tend to maintain a straight trajectory. The probability of a large droplet colliding with a small one (capture coefficient K_g) depends on their relative sizes, the viscosity of the medium (η), and the speed of movement (Fig. 6).

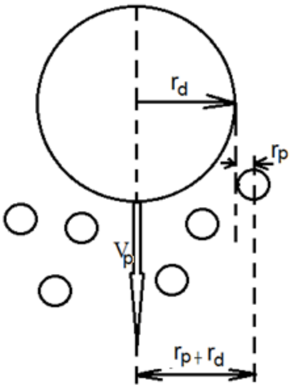

Figure 6. Schematic of the capture of dispersed particles by precipitation droplets during gravity coagulation

The description of this process is considered in[504].

The number of small particles that one large raindrop attaches to itself is defined as

$$-\left(\frac{dC_p}{d\tau}\right) = C_d \frac{\pi}{4}\int_0^R K_g \cdot (r_p + r_d)^2 \cdot V_d \cdot C_p dr_p \quad . \tag{15}$$

To determine the capture rate K_g, similarity theory is most often used (to build semi-empirical models).

In gravitational coagulation, the type of charge of the interacting particles also plays a significant role, but this effect is much smaller compared to Brownian coagulation due to the inertial forces of large droplets.

The process of soot and ash sorption by water droplets is determined by their physical and chemical properties. Since soot and ash particles have a complex structure and chemical composition, which depend on the type of fuel and combustion conditions, we will consider the main properties of soot particles and ash separately.

The high carbon content, the presence of functional groups on the surface of the particle, and the high porosity of the particle will determine the characteristics of soot absorption by liquid precipitation.

Ash particles have a completely different chemical nature from soot and are complexes of metal oxides with a spherical porous structure (Fig. 7).

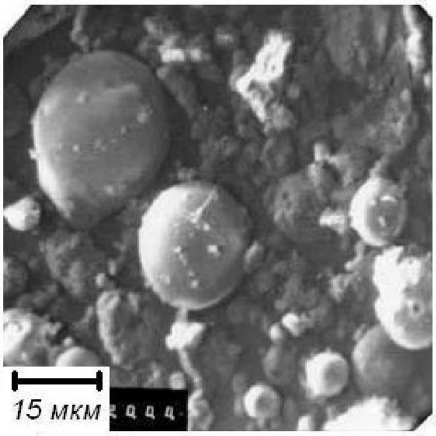

Figure 7. Micrographs of ash

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[504] Loosmore G., Cederwall R. Precipitation scavenging of atmospheric aerosols for emergency response applications: testing an updated model with new real-time data. 2004. № 38. pp. 993-1003.

The chemical composition of ash is also determined by the type of combustible and combustion conditions, but while the combustion conditions were key in the formation of soot, the oxidizer content and temperature play a much smaller role in ash, the composition of ash is mainly determined by the type of combustible. So if combustible materials are divided into groups, the chemical composition of the ash formed during their combustion can be represented as follows:

- cellulose-containing combustible materials – CaO (up to 40 %), SiO_2 (up to 32 %), Fe_xO_y (up to 20 %), Al_2O_3 (up to 8 %), MgO (up to 3 %), Na_2O (up to 2 %), oxides of titanium, manganese, phosphorus, etc;
- petroleum products – V_xO_y (up to 55 %), CaO (up to 20 %), SiO_2 (up to 12 %), NiO (up to 8 %), Te_xO_y (up to 5 %), oxides of lead, chromium, zinc, etc;
- artificial polymers – CaO (up to 32 %), SiO_2 (up to 14 %), Fe_xO_y (up to 8 %), V_xO_y (up to 7 %), Al_2O_3 (up to 4 %), MgO (up to 2 %), TiO_2 (up to 2 %), NiO (up to 2%), oxides of lead, chromium, zinc, etc.

Among the iron oxides in ash, a significant portion is magnetite (Fe_3O_4) with strong magnetic properties, which also affects the processes of ash sorption by atmospheric precipitation.

Powerful convective flows that occur over large fires can lift combustion products to heights of up to 10 km. Later, when the air flows cool down, at a distance of □ 1 km from the combustion center, they settle or, depending on meteorological conditions, hover at altitudes up to3 km. Since the main processes of precipitation occur at altitudes of 3 – 5 km, aerosolized combustion products are also involved in the process of precipitation formation over the combustion zone. However, the bulk of aerosol particles is located below the precipitation zone, where the process of condensation of water vapor on soot and ash particles practically does not occur, but rather their sorption by water droplets. Based on this, we will consider two different mechanisms: sorption of water molecules by the solid aerosol particle and sorption of the aerosol particleи by a water droplet. On carbon-containing particles, which include soot, the primary adsorption of water molecules occurs on active centers, which can be oxygen-containing and other functional groups. The process of adsorption of water vapor on the surface of soot can occur at a rather low humidity, which indicates the dominance of the electrical nature of the interaction of the functional group on the surface of the droplet with the dipole water molecule. However, the electric forces of functional groups decrease rapidly with distance and are also screened by water molecules, so this mechanism of condensation allows adsorption of up to 10 monolayers of water molecules, after which condensation stops. For this reason, soot particles are classified as hydrophobic and, therefore, are inactive droplet formation nuclei in the atmosphere. However, soot complexes formed as a result of primary condensation with a water shell should have surface properties similar to water droplets. At the same time, the size of such complexes is comparable to the size of soot particles and can reach up to $d \approx 100$ μm. Having these physicochemical properties, aquacomplexes of soot particles, when entering the upper layers of the troposphere with appropriate meteorological conditions, can act as droplet nuclei. Therefore, when taking into account the influence of soot particles on precipitation processes, they can be considered as particles with surface properties of water.

In addition, some soot particles have abnormally high hygroscopicity. According to the authors, this is due to the presence of soluble sulfur-containing compounds on the surface of soot particles. During the initial condensation, a layer of aqueous solution of sulfur-containing compounds is formed on the surface of the particle. Such soot particles are formed during the combustion of petroleum products and, depending on their properties, can act as active droplet centers.

As noted above, the most active centers of droplet formation in the atmosphere are charged particles (ions). In addition to the artificial introduction of charged condensation nuclei using chemical reagents, there are various electrophysical methods of artificial ionization of air components.

A promising method of artificial air ionization is the impact on the local volume of powerful electromagnetic radiation. The essence of this method is that air ionization occurs due to the transmission of electromagnetic radiation energy from ground sources to free molecules and electrons in the zone of influence. The advantage of this method is the possibility of creating additional ions at a considerable distance from the emitter. This will make it possible to significantly expand the meteorological conditions for applying the method of precipitation of dangerous substances from the atmosphere by artificial precipitation.

Ionizing the air at the height of cloud formation (1–5 km) on an area of up to 10 km^2 is in principle possible by irradiating the affected zone with beams of powerful electromagnetic radiation (Fig. 8).

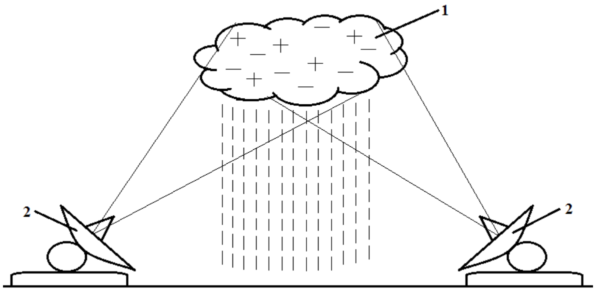

Figure 8. Scheme of remote influence on precipitation processes due to electromagnetic radiation: 1 – zone of active influence; 2 emitters

The scheme of the control algorithm of the organizational and technical method of liquidation of the consequences of emergency situations of a natural and man-made nature by localization of centers of intense combustion is presented in Fig. 9.

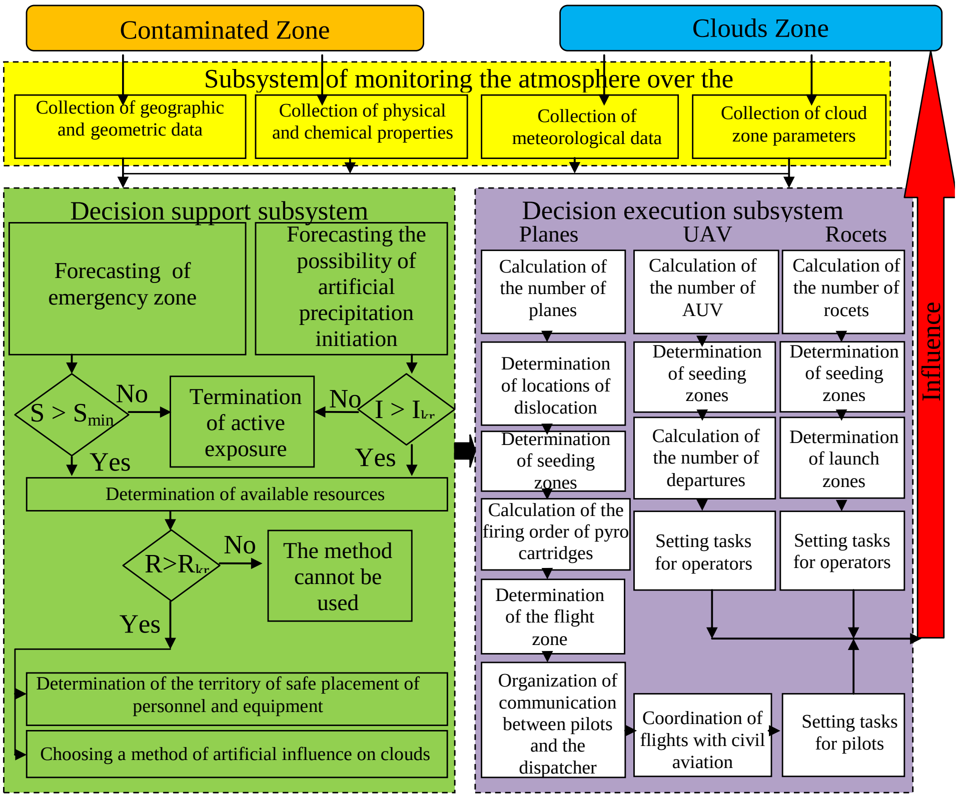

Figure 9. Algorithm for the implementation of the method of liquidation of the consequences of large-scale emergencies of a natural and man-made nature with the release of hazardous substances into the atmosphere

The use of this method involves the following procedures:

1. The monitoring subsystem collects, processes and systematizes data on: coordinates and geometric dimensions of the center of intense combustion at time τ; meteorological parameters of the atmosphere above the emergency zone (temperature distribution by height; wind speed and direction; atmospheric pressure; air humidity); coordinates, moisture content and water content of clouds potentially suitable for artificial precipitation.

2. With the help of the data received from the monitoring subsystem, the development of the combustion center is forecasted in the decision support subsystem; forecasting the intensity of precipitation over the burning zone when using one or another method of artificial air ionization. Under the condition of significant danger to the population and the environment from the consequences of an emergency and sufficient predicted rainfall intensity to eliminate the consequences of an emergency, the person making the management decision determines: priority protection areas (for example, populated areas); the territory of safe placement of personnel and equipment; the type of reagent depending on weather conditions (hygroscopic, ice-forming) and the type of chemical pollution (for neutralization and effective precipitation of dangerous substances); the required amount of reagent depending on the strength of the cloud, its water content and moisture, as well as the concentration of dangerous substances in the atmosphere that must be neutralized; method of delivering the reagent - in case of a large area of sowing and a significant amount of the required reagent, it is recommended to use manned aircraft; in the case of a small amount of the required reagent, as well as in the absence of aircraft, the use of unmanned aerial vehicles is recommended; under conditions of difficult meteorological conditions and possible danger, pilots are recommended to use small-sized rockets.

3. The data obtained as a result of the monitoring, the results of forecasting, and the management decisions made are transferred to the decision execution subsystem. The head of the solution implementation subsystem, depending on the chosen method of reagent delivery, conducts:

3.1. When using missiles: determination of the number of missiles of the corresponding class; determination of coordinates and height of sowing zones; determination of safe missile launch zones; setting tasks for rocket launch operators.

3.2. When using UAVs: calculation of the number of involved UAVs based on the available number; determination of coordinates and height of sowing zones; calculation of the number of departures, taking into account the size of the seeding zone and the number and carrying capacity of the UAVs involved; setting tasks for UAV operators.

3.3. When using manned aircraft: calculation of the required number of aircraft; determination of the available number of aircraft and their location; determination of coordinates and height of sowing zones; calculation of the frequency of launching pyro cartridges depending on their type and the required concentration of the reagent; determination of the safe flight zone. It is prohibited to fly planes through the zone of chemical or radiation pollution and under seeded clouds to prevent lightning from hitting the plane; organization of pilot communication with the controller and flight manager; flight coordination with civil aviation controllers; setting tasks for pilots.

4. An active influence on the cloudiness zone is carried out, taking into account the inertia from the sowing period to the beginning of precipitation of 15-30 minutes. and wind speed and direction.

If the conditions for the safety of the population and the environment are ensured, or if it is impossible to ensure precipitation of the required intensity, the active influence on clouds is stopped.

CONCLUSIONS

The parameters of the cloudiness zone and weather conditions are the basis for forecasting the intensity of artificially initiated precipitation. At the same time, it is necessary to compare the forecasting results for different methods of artificial influence. Taking into account the technical possibilities of using one or another method, the most effective method is selected. If the person making the decision chooses a chemical method of artificial impact on precipitation, depending on the weather conditions and the type of pollutant, the composition of the reagent is selected.

Thus, taking into account the constantly growing threats of large-scale accidents with the release of dangerous chemical and radioactive substances into the atmosphere, there is a need to increase attention to the development and implementation of new methods and methods of deposition of dangerous substances from the atmosphere. One of the promising methods can be the use of artificial precipitation over the pollution zone.