On the Survivability of Infrastructure Facilities in the Arctic During Fires

Andrey Ishchenko[a], AndreyTarantsev[a], AlexanderTarantsev[b,c]

[a]*Academy of Fire Service of EMERCOM of Russia; Borisa Galushkina str., 4, Moscow, 129366, Russian Federation,*
[b]*Solomenko Institute of Transport Problems of the Russian Academy of Science 13, line 12, Vasilyevsky Island, St. Petersburg, 199178, Russian Federation,*
[c]*Saint Petersburg University of State Fire Service of EMERCOM of Russia, Moskovskiy prospect 149, Saint-Petersburg, 196105, Russian Federation*

Abstract
The issues of ensuring stability during fires of infrastructure facilities in northern latitudes are considered. The risk of failure of various modules (residential, warehouse, household, energy supply, etc.) in case of fires and the impact of this on the target functions and personnel of objects is shown. The concept of survivability of Arctic objects in the event of fires is introduced and the main indicators of survivability are formulated. The necessity of maximum operational containment and extinguishing of fires at the above-mentioned objects in order to ensure the necessary level of their survivability is justified.

Keywords
Arctic objects, infrastructure, fire, survivability

1. Introduction

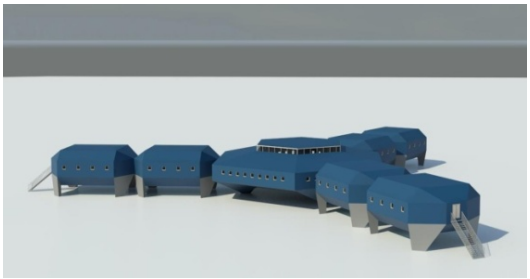
[1]The current stage of development of our country involves the intensive development of the Arctic Zone (AZ) and the regions of the Far North (FN). The consequence of this is the need to create a sustainable transport infrastructure – the reconstruction and construction of sea and river ports, airports, land transport highways, etc. [1-3]. It is planned to create a network of various objects in the AZ and on the FN - weather stations, communication systems, research stations, power facilities, etc.

The extremely difficult conditions of the Arctic and the North (low temperatures, winds, snow zones, permafrost) suggest the modularity of the structure of objects (Figure. 1), which allows it to be developed and expanded with modules of various functional purposes – residential, warehouse, administrative, industrial, energy supply, etc.

2. Fire risk, extinguishing and survivability of Arctic objects

Arctic modules of various functional purposes have two common features: a) high energy saturation (the ratio of circulating power to volume, an order of magnitude greater than similar rooms in a temperate climate); b) reduced fire resistance [3, 4].

a



b

Figure 1: Modular objects in AZ: a - operating with cylindrical universal blocks, b - designed with octagon modules

This largely explains the statistics of fires and emergencies at the beginning of the 21st century, characterized by a high risk of damage to the modules and the equipment and material values contained in them [5-7].

Intelligent Transport Systems. Transport Security - 2021, May 14, St. Petersburg, Russia
EMAIL: adinko@mail.ru (A.D. Ishchenco); dask_cradle@mail.ru(A.A. Tarantsev);t__54@mail.ru (A.A. Tarantsev).
ORCID: 0000-0002-4424-2840 (A.D.Ishchenco); 0000-0003-3605-373X (A.A. Tarantsev); 0000-0003-1561-2483 (A.A. Tarantsev).

Data on the accident rate of objects in AZ are shown in Table 1. As statistics show, fires and explosions pose the greatest threat to Arctic objects.

A feature of the fire in the Arctic module is the rapid growth of hazardous factors (HFF) [4] due to the limited volume and its high energy saturation. Extinguishing the fire with the use of well-known tactics [8] by the links of the gas and smoke protection service (GSPS) is complicated:

- low outdoor air temperatures and the exceptional complexity of using water [9];
- the inability to provide operational assistance from outside due to limited transport accessibility (long distances between objects, snow drifts, non-flying weather, etc.) and remoteness from large settlements and Arctic rescue centers (ARC) of EMERCOM of Russia;
- a limited number of personnel (each member of the staff is required to possess several additional specialties, including firefighter and paramedic).

As a result, a fire can lead to significant damage (Figure 2) [10] up to the loss of the functional purpose of the object and a threat to its personnel.

Table 1
Data on accidents at facilities in AZ

Accidents and emergencies	Ratio
Collapses and fires in residential and administrative buildings	21-39%
Explosions and fires of technological equipment	18-39%
Transport accidents	25-32%
Accidents on utility networks and life support systems	7-15%
Accidents with the release of toxic and chemically dangerous substances	8-12%
Pipeline accidents	4-8%

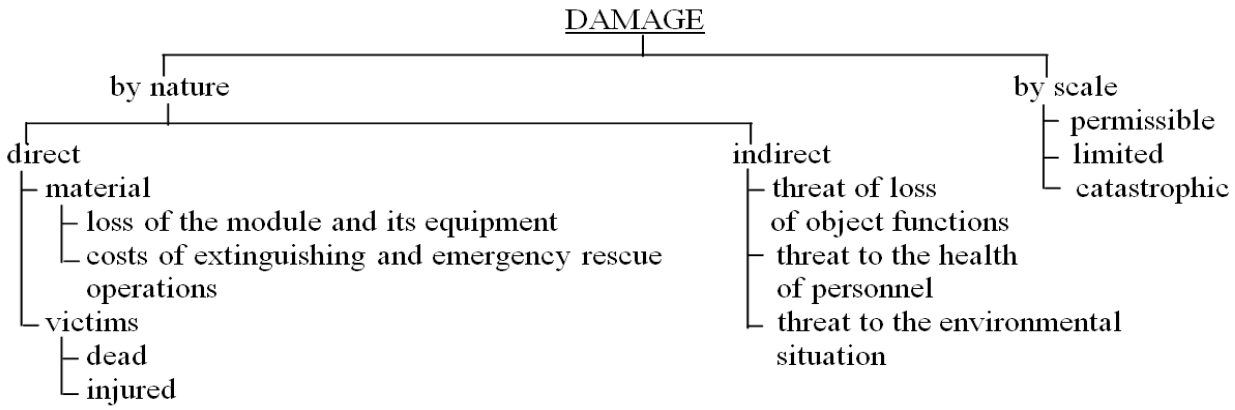


Figure 2: Structure of fire damage at a modular Arctic facility

This poses the task of developing a fundamentally new method of fire containment and extinguishing in the module, which does not require the use of water and the use of expensive Arctic fire equipment. Also important requirements are high efficiency (the module can be irretrievably damaged after a few minutes of free development of the fire) and safety for the participants of extinguishing.

With the participation of the author of the article, such a method was proposed, justified and patented [11, 12]. Its essence is that the module is equipped with a built-in fan at the end, which is closed by a hatch in the initial position, and another normally closed hatch is located in the opposite end of the module. If a fire occurs, the hatches are opened, and the fan turns on, blowing the volume of the module with external low-temperature air. This leads to a sharp decrease in the average volume temperature, flame failure, removal of HFF from burning module, slowing down the combustion and thereby containing the fire. Arrived firefighters enter the module from the fan side and extinguish it with primary fire extinguishing means (PFEM) under the protection of a low-temperature jet – as calculations and experiments have shown, the HFF will be removed from the gap between the fire source and the fan [13, 14], firefighters will be able to work even without respiratory and visual protection. To speed up the extinguishing by other participants of the extinguishing, snow can be dosed on the fan from the outside. In fact, this is a new tactic for extinguishing fires in the modules of Arctic objects.

As an explanation, Tables 2-4 show the comparative effects of extinguishing fires by known and proposed methods on the example of some types of modules – residential, economic and energy-supplying. Taking into account the above, it seems appropriate to introduce a new concept of "survivability of a modular Arctic object in case of fire". By analogy with the well – known formulation

of Admiral S. O. Makarov: "the survivability of a ship is the ability of a ship to fight when some of its parts are damaged by the enemy", the following formulation can be proposed: "the survivability of a modular Arctic object in a fire is the ability of an object to perform its functions when some of its modules are damaged by fire".

Table 2
Comparative effect of the new tactics of extinguishing the residential module

Conditions fires	***Extinguishing***	**Damage**	**Influence on the object (%)**
The staff is in a waking state	*Application PFEM, arrival of the duty shift department*	Minor, minor repairs are required	Minor (up to 5%)
	application of the PFEM, switching on the purge system		
There are no staff, the APS has worked	*Arrival of the duty shift department, extinguishing by GSPS, ERO links*	Significant, module failure	Average, it is necessary to relocate people (15-20%)
	Switching on the purge system, eliminating combustion by the forces of the duty shift department	Minor, minor repairs are required	Minor (up to 5%)
People in a state of sleep	*Possible poisoning by combustion products, extinguishing by GSPS links, conducting ERO*	Medical assistance is required, the module is out of order	Significant, some specialists are lost, urgent medical care is required (50-80%)
	Switching on the purge system, evacuation, elimination of combustion by the forces of the duty shift department	Minor, minor repairs are required, there are no victims	Minor (up to 5%)

ERO – emergency rescue operations

Table 3
Comparative effect of applying a new extinguishing tactic in case of a fire in a food hall

Conditions fires	**Extinguishing**	**Damage**	**Influence on the object (%)**
Short circuit in the electrical equipment of the brew house	The use of PFEM personnel, extinguishing by GSPS links	Medium, requires module repair, repair (replacement) of equipment	Average, temporary transition to dry rations (20-30%)
	Switching on the purge system, eliminating combustion by the forces of the duty shift department	Minor, minor repairs are required, the main equipment is preserved	Minor, power schedule shift (up to 15%)
Grocery warehouse without permanent jobs	Arrival of the duty shift department, extinguishing with GSPS links, conducting ERO	Some of the products are damaged, the warehouse is out of order	Significant, power outages, food delivery is required (50-70%)
	Switching on the purge system, ERO, elimination of combustion by the forces of the duty shift department	Minor, products are saved, minor repairs are required	Minor (up to 15%)

Table 4
Comparative effect of the new tactics of extinguishing the energy module

Conditions fires	**Extinguishing**	**Damage**	**Influence on the object (%)**
Short circuit in the electrical panel, cable industry	Disconnection of electrical equipment, use of PFEM by personnel, extinguishing and conducting ERO by GSPS links	Significant, requires repair or replacement of equipment, partial failure of the module	Partial loss of functions due to de-energization of the object, deterioration of heating (40-60%)
	Disconnecting electrical equipment, switching on the purge system, eliminating combustion by the forces of the duty shift department	Minor, minor repairs are required, the module is saved	Minor, temporary power outage (up to 10%)
Fuel leakage and ignition	The threat of a flash or explosion, disconnection of the fuel supply, the use of PFEM by personnel, extinguishing and conducting ERO by	Significant, requires repair or replacement of equipment, partial failure of the module	Temporary de-energization of the object (30-50%)

	GSPS links		
	Switching off the fuel supply, switching on the purge system, eliminating combustion by the forces of the duty shift department	Minor, minor repairs are required, the module is saved	Minor, temporary power outage (up to 10%)
Scheduled or unscheduled repairs, welding work	Disconnection of electrical equipment, application of PFEM, extinguishing and conducting ERO by GSPS links	Significant, requires repair or replacement of equipment, partial failure of the module	Temporary de-energization of the object (30-50%)
	Switching off the fuel supply, switching on the purge system, eliminating combustion by the forces of the duty shift department	Minor, minor repairs are required, the module is saved	Minor, temporary power outage (up to 10%)

At the same time, the impact of a fire on the survivability of an Arctic object can be (see Tables 2-4):

- insignificant (the object has not lost its main target functions, the staff has practically not suffered),

- marginal (some functions of the facility have been partially lost and can be restored on their own, a small number of personnel have suffered);

- catastrophic (the object has lost its functional purpose, which can be restored only after external assistance, there is a threat to the life and health of personnel, there are victims).

The survivability of the Arctic object will largely depend on two factors:

a) in the mode of what functional purpose the fire occurred and whether the staff is awake there;

b) how much damage was caused to the module.

Quantitatively, the survivability of a modular Arctic object in a fire can be estimated by three indicators: the probability of p_f performing its functions, the time $t_м$ for restoring functions, and the number of affected N_p.

3. Conclusion and future work

Thus, the paper describes the design features and operating conditions of infrastructure facilities n the AZ and in the FN; a fundamentally new tactical method of fire containment and extinguishing by purging the module volume with external low-temperature air, followed by the penetration of firefighters into the module and safe operation there, as well as with a metered supply of snow to accelerate extinguishing; shows the critical impact of a fire in an energy module on the functionality of the object and the safety of its personnel; a new concept of "survivability of an Arctic object" is introduced and justified.

In the future, it is planned to cover these issues in more detail and formulate recommendations to designers of modular Arctic facilities and officials responsible for fire and general safety of such facilities.

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