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ABOUT DEVELOPMENT OF BASE COMPONENTS OF THE INTERNATIONAL PLANETARY DEFENCE SYSTEM "CITADEL"

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ABSTRACT

Creation of the International Planetary Defence System (PDS) can be considered a possible way of counteraction against asteroid-comet hazard. The basis of this system can be represented by the Level for Short-term (operational) Reaction (LSTR) called "Citadel-1" (means for active defence) and the Forecasting Service of areas and consequences of dangerous celestial bodies (DCBs) falls (means for passive defence). Results LSTR components development are presented. It is shown that modern rocket-space and nuclear technologies provide for creating defence from asteroids of up to several hundred meters in size, similar to the 2015 PDC hypothetical asteroid. Since the PDS has not yet been created, minimisation of damage from possible collisions by the creation of the Forecasting Service of areas and consequences of DCBs falls becomes increasingly important. Results of quantitative assessments of possible damage from affecting factors of the 2015 PDC asteroid fall are presented. They were obtained through test simulation of the developed demonstration model of the Forecasting Service software system.

Keywords: *planetary defence system, civil defence, forecasting, simulation*

1. Means of active defence

One of possible ways of counteractions against asteroid-comet hazard can be the creation of the International Planetary Defence System (conventional name "Citadel") [1-4]. A basis of this system can be presented by the Level for Short-term (operational) Reaction called “Citadel-1” [5-7] and the Forecasting Service for areas and consequences of dangerous celestial bodies falls [8].

The LSTR is designed for protection from DCBs, which can be detected several days-years before collision. The LSTR has to incorporate the international ground- and space-based Surveillance Service, two regional Planetary Defence Centres (PDC) and, accordingly, two regional segments of the reconnaissance and interception service – the European-Asian “East” and the American “West”, missile and space systems which should be based on the cosmodromes, located in the eastern and western hemispheres.

The basis for the ground- and space-based surveillance service will be formed by the space surveillance segment. The regional segments of the ground- and space-based reconnaissance and interception service are designed for clarification of the DCB characteristics with the reconnaissance spacecraft (SC) and for deflection of DCB off the impact trajectories or destruction of DCB by intercepting SC.

The ground- and space-based reconnaissance and interception service must contain:

- rocket-space complexes with the reconnaissance spacecraft and intercepting spacecraft;
- ground-based infrastructure incorporating the launch preparation hardware of the spacecraft, the launch itself and their control.

Let’s take the hypothetical 2015 PDC asteroid as an example for considering the scheme of the LSTR operation.

The first task to be resolved after the discovery of a potentially hazardous asteroid is to specify its trajectory and physical characteristics. The most effective way of solving this problem is to launch a reconnaissance spacecraft to the asteroid.

The reconnaissance SC of the small class is designed for studying DCBs. Latest achievements of the world cosmonautics are planned to be used for its development. This will allow to develop the SC with the minimum dimensions and mass characteristics (and mass of about 100-200 kg).

On approaching the DCB, the reconnaissance SC by using the detection equipment will provide input data required for building of the engineering model of the dangerous asteroid. On the basis of the model a scheme of the interception and the action on the DCB will be developed.

If the LSTR was established before the moment of the 2015 PDC detection, the reconnaissance SC could be launched without waiting for the optimum launch date. For example, estimates indicate that if launch vehicles such as Proton, Ariane 5 and a number of others will be used, the reconnaissance SC can be launched 1 July 2015 and will approach the asteroid 30 December 2016. Thus, if the collision will confirmed we will have a significant time reserve to make the best decision for the defence of the Earth from the 2015 PDC, Since the LSTR has not yet been established, it will take time to create a reconnaissance SC. Given the situation of emergency, we can hope that such SC can be created by the end of 2016. If the SC are launched in the period from October 2016 to January 2017 they will reach the 2015 PDC asteroid in December 2017 (Fig. 1).

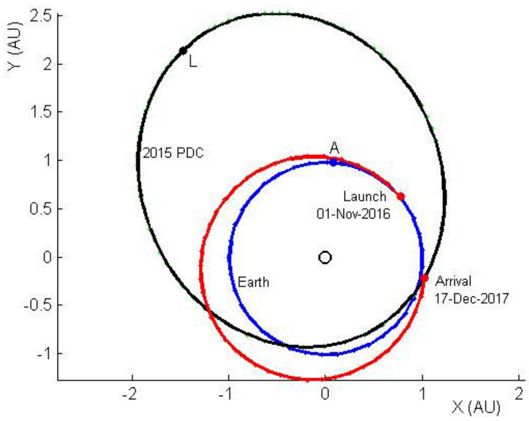

Fig. 1 The trajectory of the reconnaissance spacecraft flight

Thus, all necessary data for the optimal choice of means of action on the DCB will be obtained during the flyby.

For action on DCBs, different technologies are being considered. Nuclear and kinetic means are most efficient at the operative interception [9-14]. They allow to destroy asteroids of about 500 m in diameter and to deflect larger celestial bodies with using modern launch vehicles,

The optimum time for launching an intercepting SC is the end of 2018. The time reserve of 3.5 years, gives opportunity to, hopefully, create the SC during this period of time. Characteristic energy C3 of these SC will be 15-20 km^2/s^2. This gives possibility to launch a spacecraft weighing about 4000 kg by Proton launch vehicle, Atlas V and a number of others [15]. The mass of a nuclear device will be about 1,000 kg [6], and its capacity – 1-2 Mt [16,17].

Depending on the type of nuclear explosion (standoff, surface or subsurface), the momentum transferred to the asteroid may be from 10^9 to 10^{13} kg m/s for 1 Mt [18]. If the 2015 PDC asteroid diameter is 500 m and its density – 2.7 kg/m^3, its mass equals to 1.8 10^{11} kg. In this case, the velocity impulse acquired by asteroid surface ranges from 5 mm/s to 0.5 m/s, (standoff explosion), 0.5 m/s (surface explosion), from 5 to 50 m/s (subsurface explosion).

The type of explosion will be selected not only to provide the needed velocity impulse of the asteroid, but also to avoid its destruction. For this purpose, several consecutive standoff explosions can be used providing a "soft" impulse on the asteroid.

Fig. 2 shows a possible version of the intercepting flight to the 2015 PDC asteroid. Possible launching date can be 5 October 2018, and the arrival date 26 April 2020.

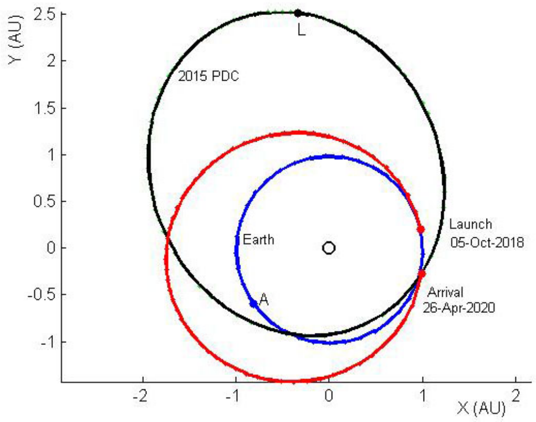

Fig. 2 The trajectory of the spacecraft-interceptor flight

When approaching the DCB the interception module separates from the spacecraft and heads for the DCB with the aid of vernier engines. The orbital module continues its motion and observes the interception process (Fig. 3).

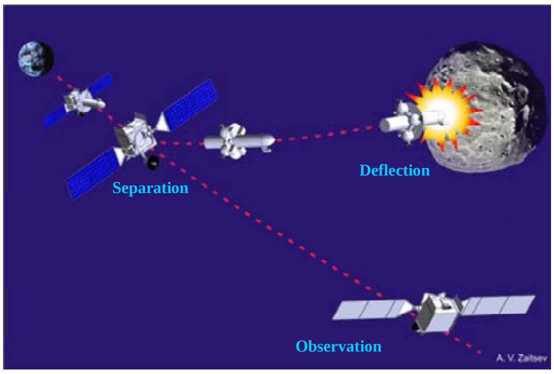

Fig. 3 The scheme of the DCB interception

The asteroid flight outside the capture radius of the Earth must be ensured by selecting required velocity impulse on it. In case of 2015 PDC, the capture radius will be about 9000 km. Therefore, taking into account some margin it is necessary to ensure deviation of about 15,000-20,000 km from the centre of the Earth. Calculations show that if the impact on to asteroid is produced at the end of April of 2020, the change of velocity must be about 50 mm/s (see Table 1).

Table 1. Minimum distance of the 2015 PDC from the Earth depending on the value of velocity impulse in the direction of velocity

Impulse (mm/s)	Date of maximum approach	Minimum distance from the Earth centre (km)
500	2022 09 03.36621	209799
50	2022 09 03.18982	19097
10	2022 09 03.17043	3037
5	2022 09 03.16759	1485
0	2022 09 03.16494	541

It is important to realize that any change of the orbit of a dangerous body in order to eliminate an immediate threat, can lead to resonant returns (or non-resonant approaches) or even a collision in the future. This potential danger has not been investigated in the present work.

Estimates show possibility of the Earth defence from such as 2015 PDC asteroids with the lead time of about 5-7 years. It is necessary to establish a permanent LSTR to protect the Earth against asteroids with a shorter lead time.

If necessary it would be possible to build quickly the level of long-term reaction for protection from larger DCBs on the basis of the LSTR. It will allow to completely solve the problem of the Earth defence against asteroids and, partially, comet hazard (withy nucleuses of 0.5 to 1 km in size).

Results of the research allow to make a conclusion, that Russian and foreign technologies allow starting practical development of the International PDS against the asteroid-comet hazard. The PDS “Citadel” project can become the first one in this area.

2. Means of passive defence

Since the PDS has not yet been created, the analysis of probabilities and risks and the minimisation of damage from possible collisions become increasingly important. For mitigating the damage, it is necessary to determine in advance location, time and explosive power of the collision and also affecting factors and their consequences for the population and territories. For this purpose, a Forecasting Service of areas and consequences of DCBs falls should be created [8,19].

Under orders of the Ministry of Emergency Situations of Russia, the Planetary Defence Center together with A. A. Blagonravov Mechanical Engineering Research Institute, Institute of Applied Astronomy RAS, Institute of Geosphere Dynamics of RAS, Russian Federal Nuclear Center (RFNC–VNIITF) and Extreme Situations Research Center LTD, has developed principles of construction of such Service. A software system is the most important element of this Service. It combines a variety of computer programs that simulate catastrophic scenarios associated with the asteroid and comet falls. It has to ensure:

- the determination of conditions of an entry of the celestial bodies in an atmosphere of the Earth and their characteristics;
- the calculation of the motion in the atmosphere and the place of the hitting (explosion);
- the assessment of explosion power in the atmosphere, on the surface and in the water;
- the assessment of expected consequences for the surface infrastructure and biosphere.

Threat of asteroids and comets belongs to those natural factors that can be discovered beforehand, which makes it possible for the Ministry of Emergency Situations to undertake a number of measures on minimizing the potential losses (i.e. evacuation o people, material and cultural assets, and hazardous materials and facilities). This can be done if the place and time of explosion are estimated with sufficient accuracy.

These measures realization is possible only through broad international cooperation. It is reasonable to have two regional segments of international Service – Eurasian and American – with each having its Forecast Centers. The Service should include Cosmic Observance Segment, optical and radar ground instruments, regional forecast centers and communication channels between all components of the Service. After creation of offered Service, it becomes an important component of the future ~~of~~ Planetary Defence System.

Results of quantitative assessments of vulnerability and possible damage to the ground infrastructure and the Earth’s biosphere from affecting factors of an asteroid of 2015 PDC type falling are presented below. They were obtained while test simulation of the demonstration model of the developed software system.

As an example, we present consequences of falls of two hypothetical asteroids, which may collide with the Earth in September 3, 2022 on the territory of Thailand and India. Parameters of hypothetical asteroid that would fall on Thailand's territory:

Latitude - 19.93° N
Longitude - 100.19° E
Asteroid's diameter - 250 m.
Asteroid's density - 2,600 kg/m^3
Velocity of the asteroid - 15.98 km/s
Angle of incidence - 43.7°

Such asteroid may damage more than 100 settlements in Thailand, Myanmar and Laos (Fig. 4). On this and following figure: blue - no damage; green - low damage; yellow - medium damage; red - high damage; dark red - destruction; black - collapse. The radius of affected territory will be 120 km. In this case, potential human losses will be: fatalities - 12,540, injured - 26,150 and total - 38,690.

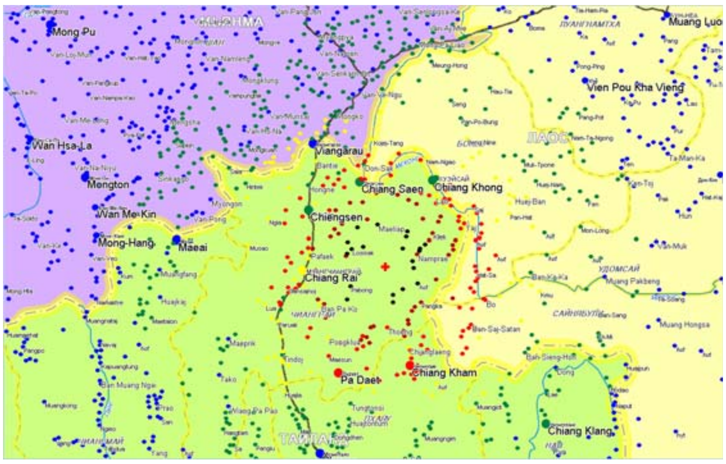

Fig. 4. Average damage states of built environment in settlements caused by the fall of a hypothetical asteroid in Thailand.

The fall of a larger asteroid in India will result in greater damage and human losses. Parameters of hypothetical asteroid that would fall on India's territory

Latitude - 27.78° N
Longitude - 80.69° E
Asteroid's diameter - 500 m.
Asteroid's density - 2,600 kg/m^3
Velocity of the asteroid - 16.05 km/s
Angle of incidence - 28.4°

Such asteroid may damage more than 1000 settlements in India and Nepal (Fig. 5). The radius of affected territory will be 200 km. Potential human losses will be: fatalities - 266,320, injured - 507,830 and total - 774,150.

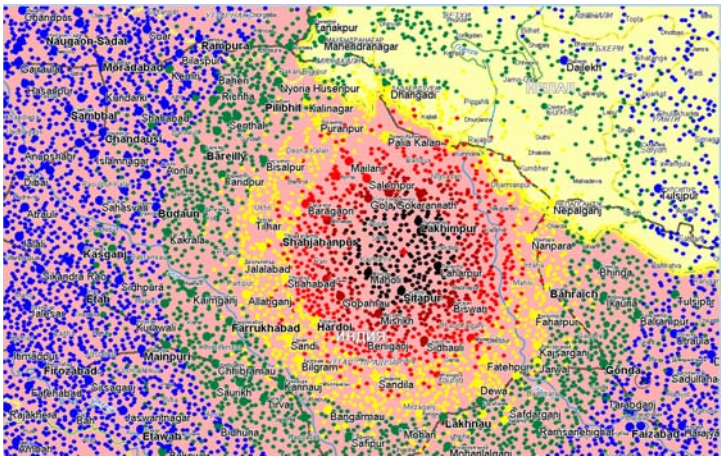

Fig. 5. Average damage states of built environment in settlements caused by the fall of a hypothetical asteroid in India.

On the basis of these data, forces and means of national and international services of civil defence will develop measures for mitigating possible damage and eliminating emergency situations. First of all, evacuation of population, material and cultural values, and also dangerous materials and objects from the expected areas of DCB's falls belongs to these actions.

3. Summary.

The carried out estimates show feasibility of the development of the Earth protection against asteroids of 2015 PDC type for the lead time about 5-7 years. For this purpose, nuclear explosive devices are the most effective means for impact on an asteroid. However, in some cases, for long lead times and small size asteroids, also kinetic devices can be used as means for action.

For defence from asteroids with shorter times of approach, creation of a permanent Level for Short-term Reaction of the "Citadel-1" type is needed.

In addition, prior to the creation of the Planetary Defence System, it is necessary to create a Forecasting Service of areas and consequences of dangerous celestial bodies falls. At early detection of danger, it will allow to carry out actions by forces and means of civil defence for mitigating damage from damaging factors resulting from these objects falls.

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