THE ANALYSIS OF POLLUTION OF A SPACE IN THE FIELD OF LEO AT VARIOUS SCENARIOS OF ITS FURTHER DEVELOPMENT

I.V.Usovik(1), S.S. Loginov(1), M.V. Yakovlev(1), A.I.Nazarenko(2)

(1)Central Research Institute of Machine Building, Pionerskaya str., 4, 141070, Korolev, Russia
(2) Scientific and Technological Center KOSMONIT, Profsoyuznaya str. 84/32, 117997, Moscow, Russia

ABSTRACT

Making of adequate administrative and technological decisions in reply to the threats caused by space debris (SD) is one of the tasks, which must be solved already now. To justify accepted decisions it is necessary to have forecasts of contamination of the near-earth space for various scenarios of its further exploration.

This report considers forecasts of near-Earth space (NES) contamination for optimistic and pessimistic scenarios of further NES exploration, including consideration of various measures on mitigating the man-made contamination of NES. In the course of studies the authors have used the last version of the Russian space debris model SDPA, whose parameters were updated for the end of 2012.

1 INTRODUCTION

At present, the world community is anxious by the problem of growing contamination of the near-Earth space, in the region of low-altitude and geostationary orbits especially. In this connection, the countries actively engaged in space activity carry out a rather great numbers of works in the direction of modeling space debris evolution [1] for estimating NES contamination in the future. Already now a great number of measures are undertaken on limiting further contamination of NES, and the techniques of active eliminating space debris objects are elaborated. For estimating the efficiency of given measures, as well as for making administrative decisions on solving space debris-related problems, it is necessary to have a possibility of performing space debris evolution modeling taking into account various scenarios of further exploring the outer space.

With using the domestic space debris model – Space Debris Prediction Analysis (SDPA) – the calculations of change of SD evolution were carried out for various scenarios of the further space activity. The initial data for SD evolution modeling are space exploration scenarios, in which the following information is specified in some manner: the future spacecraft (SC) launches, the measures on limiting NES contamination, as well as the plans on active effect on space debris objects, and characteristics of the current SD population. Based on forecasts' data, the conclusions are drawn about contamination sources' effect on the SD evolution and on the effect of undertaken activities on limiting the NES contamination.

2 INITIAL DATA AND SCENARIOS FOR MODELING

In making forecasts it is necessary to take into account the data on the state of space debris population. The set of these data was obtained for the end of 2012 with using the SDPA model. The initial data are described in sufficient details in [2].

In forming scenarios of further space exploration the authors took into account the IADC recommendations as well as the history of spacecraft launches over the preceding time interval. Three groups of measures directed at lowering the NES contamination level were considered, namely:

- exclusion of explosions of newly launched SCs and launch vehicles (LVs);
- minimization of a number of newly generated operational elements;
- limiting the time of ballistic flight of SCs and LVs.

Taking into account these and other recommendations, the following scenarios were developed:

SD sources	Scenarios			
	1.Ideal	2.Real	3.Real optimistic	4.Real pessimistic
New launches	no	no	as before	as before
SCs and LVs explosions	no	no	no	as before
Collisions	no	> 1 cm	> 1 cm	> 1 cm

Table 1. Scenarios taking into account mutual collisions of objects.

The given set of scenarios allows one completely enough describe the effect of each of sources of generation of SD on its evolution and draw conclusions on productivity of measures undertaken for restricting the NES contamination.

As a modeling interval we will use the interval equal to 50 years that is comparable with the period of active space exploration by mankind.

Proc. '6th European Conference on Space Debris'
Darmstadt, Germany, 22–25 April 2013 (ESA SP-723, August 2013)

3 MODELING RESULT AND THEIR ANALYSIS

Consider scenario No. 1. This scenario is expedient to be used for comparing the space debris models and for estimating the situation that would take place, if we could in any way ensure the conditions corresponding to the given scenario. It is supposed that debris generation does not occur, and SD evolution proceeds due to the effect of objects' drag in the atmosphere only. This scenario is idealized, since it is clear that, owing to various reasons, even if we will completely stop launches of new space objects (SOs), the events of mutual collisions and explosions of already launched vehicles will continue to occur for some time.

For convenience of presenting the results we sub-divide all SD objects into three groups. The first group will include the objects, the largest part of which is cataloged and tracked by Space Surveillance System's (SSS) means. We will mark them with red color. In case of collision of these objects between each other a great number of new SD fragments is formed, as it was seen in the example of collision of Cosmos and Iridium satellites. The second group will include the objects, collision with which can result in complete or partial violation of functioning of active SCs. These objects are absent in the catalog; we will mark them by dark yellow color. The third group will include all small-size SD fragments, whose effect is prevented by installing special protective structures; we will mark them by green color. Thus, one can make the following table:

Group 1: Red	Group 2: Yellow	Group 3: Green
d>10 cm	d=[1-10] cm	d=[0.1-1] cm

Table 2. Group of size of space debris.

The results of SD evolution modeling with allowance for scenario 1 are presented below.

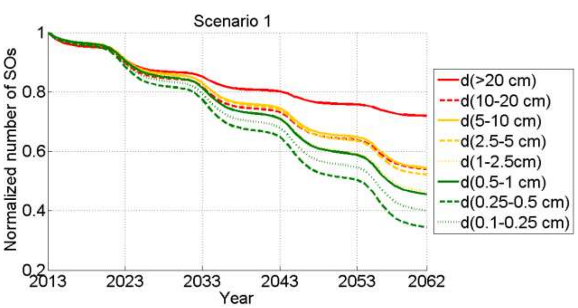

Figure 1. Scenario 1. Forecasting of a number of various-size SD objects.

As seen from the results of forecasting for 50 years, the number of objects regularly decreases. About 70 % of the number of SD objects having size > 10 cm (from the red group), which are located now in the LEO region, will retain after 50 years. This fact testifies to a low rate of natural NES purification from large-size objects as a result of atmospheric effect, that is a consequence of small values of ballistic coefficients for these objects. The number of objects with size of 1-10 cm (from the yellow group) will lower 2 times approximately. This fact testifies to the situation, where the LEO region is rather fully purified from objects of the given class due to atmospheric drag, but, nevertheless, the number of retained (in space) objects of this type is still considerable. The objects with sizes from 0.1 to 1 cm (from the green group) burn down in the atmosphere in the largest quantity, that is associated with great, as compared to the other groups, values of ballistic coefficients.

Thus, in the idealized case the NES contamination will decrease after 50 years by a factor of 2, on the average. However, the given scenario does not match to reality: it is idealized. Using it, we can estimate extremely admissible result of NES purification in the LEO region. That is, if all measures on preventing NES contamination will allow reducing the formation of new objects down to zero, the impurity will lower just in this manner. The scenarios we have developed do not take into account the active elimination of SD objects, since, as compared to the total impurity level, the number of such objects is low. The main objective of active elimination may be preventing the events similar to collision of Cosmos and Iridium satellites, after which a considerable quantity of new SD objects was formed. Therefore, even with allowance for active elimination, it will not be possible to improve the results presented in figures 1 and 2.

Scenario No. 2 is closer to reality. In the given scenario the only source of NES contamination in the LEO region is supposed to be mutual collisions of objects with sizes > 1 cm. The results of modeling with using the given scenario are presented in figures below.

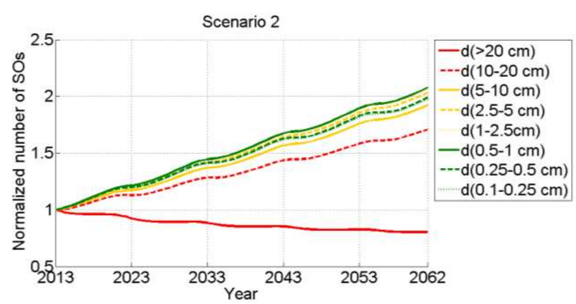

Figure 2. Scenario 2. Forecasting of a number of various-size SD objects.

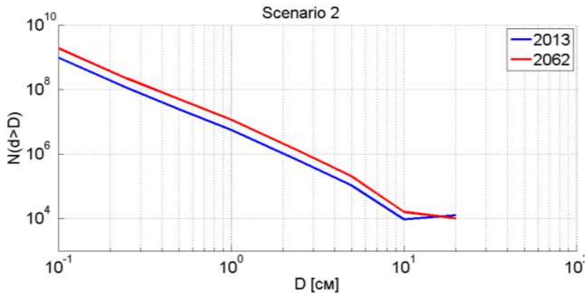

Figure 3. Scenario 2. Forecasted size distribution of SD in 2062.

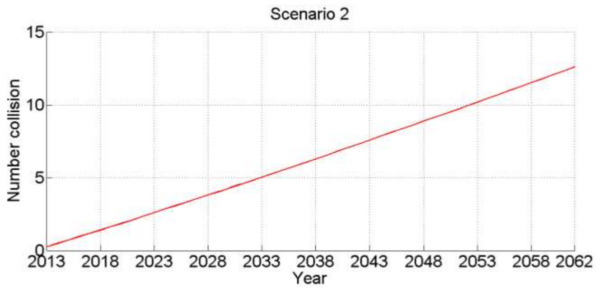

Figure 4. Scenario 2. Forecasted number of collisions since 2013 to 2062.

As seen from presented plots, with allowance for mutual collisions the number of objects with sizes > 20 cm will decrease; however, as a result of mutual collisions, the number of objects of smaller sizes will increase from 1.5 to 2 times. On the considered interval one can expect about 12 mutual collisions of objects with size >20 cm and much more mutual collisions of small-size objects with large-size ones and small-size objects with small-size ones.

It follows from presented results that in the case of termination of launches in the future, the population of objects of size 0.1-20 cm will increase sizes owing to mutual collisions. One can also draw the conclusion that over the forecasting interval the intensity of formation of given objects is much greater, than the intensity of their burning-down in the atmosphere.

Consider now the real scenario 3, in which the further utilization of NES is taken into account. We will suppose that the intensity of launches of new objects corresponds to the average indicator for 50 years of active space activity. The results of modeling with using scenario No. 3 are presented in figures below.

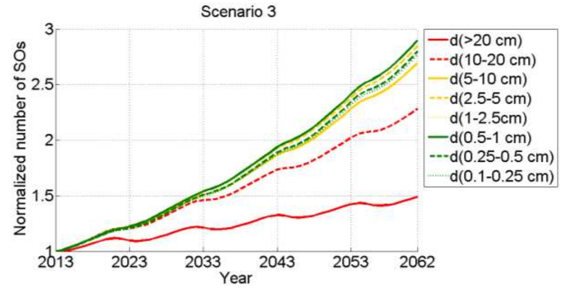

Figure 6. Scenario 3. Forecasting of a number of various-size SD objects.

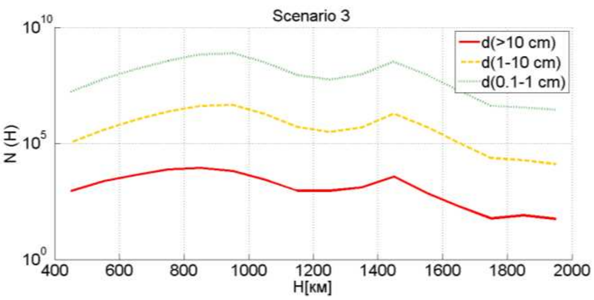

Figure 7. Scenario 3. Forecasted altitude distribution of various-size SD in 2062.

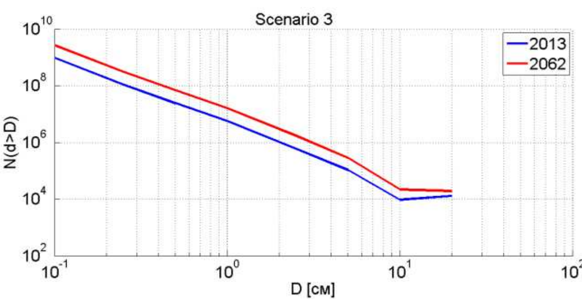

Figure 8. Scenario 3. Forecasted size distribution of SD in 2062.

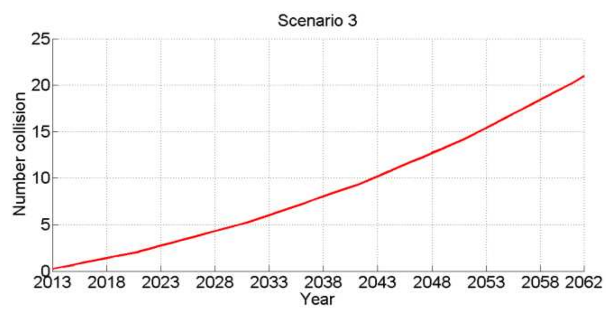

Figure 9. Scenario 3. Forecasted number of collisions since 2013 to 2062.

As seen from modeling results, with allowance for continuation of NES exploration with the same intensity, as in previous time, the number of objects from the red group will increase by a factor of ~1.9. The number of objects from the yellow and green groups will increase by a factor of ~2.75 on the average. The number of collisions, as compared to scenario No. 2, will increase ~2 times. Proceeding from the comparison of scenarios 2 and 3, one can conclude that, with further NES utilization in the LEO region at the same intensity, the contamination with large-size objects will grow.

Consider now the pessimistic scenario No. 4. In this scenario, in addition to scenario No. 3, the fact is added, that measures on mitigating the NES impurity are not fulfilled, and the formation of a new SD as a result of explosions is taken into account. The modeling results are presented in figures below.

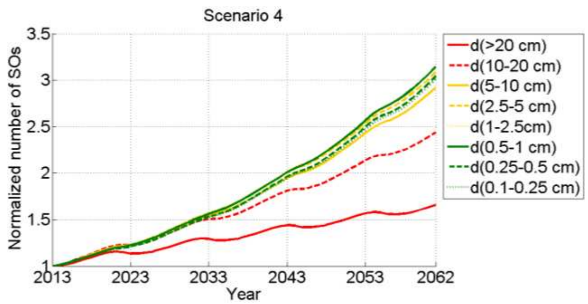

Figure 10. Scenario 4. Forecasting of a number of various-size SD objects.

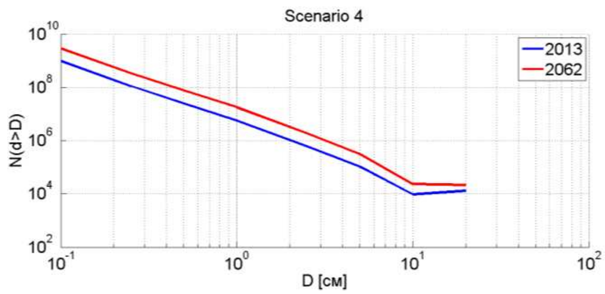

Figure 11. Scenario 4. Forecasted size distribution of SD in 2062.

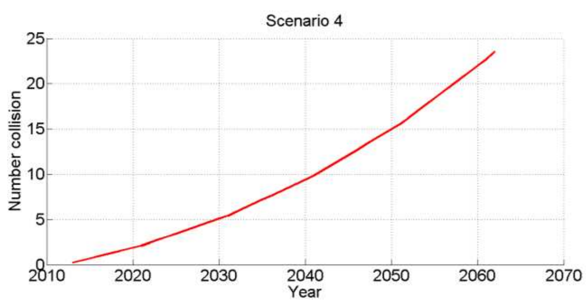

Figure 12. Scenario 4. Forecasted number of collisions since 2013 to 2062.

As seen from these plots, the growth of NES contamination increases as compared to scenario3. The number of objects from the red group will increase by a factor of ~2. The number of objects from the yellow and green groups will increase by a factor of ~3 on the average. The number of collisions will increase as much as twice as compared to scenario No. 3. Proceeding from the comparison of scenarios 3 and 4, one can conclude that in the case, if the measures on preventing the NES impurity are not undertaken, the contamination of space the room will grow according to exponential laws.

Number of SOs	<1 cm	1 cm – 10 cm	> 10 cm
in 2012	$1{,}09*10^9$	$6{,}28*10^6$	22716
in 2062	$4{,}23*10^8$	$2{,}89*10^6$	14070
Ratio	0.39	0.46	0.62

Table 3. Scenario 1. Change of a umber of various-sizes SOs over the forecasting interval.

Number of SOs	<1 cm	1 cm – 10 cm	> 10 cm
in 2012	$1{,}09*10^9$	$6{,}28*10^6$	22716
in 2062	$2{,}18*10^9$	$1{,}30*10^7$	26268
Ratio	2	2,07	1,20

Table 4. Scenario 2. Change of a umber of various-sizes SOs over the forecasting interval.

Number of SOs	<1 cm	1 cm – 10 cm	> 10 cm
in 2012	$1{,}09*10^9$	$6{,}28*10^6$	22716
in 2062	$3{,}05*10^9$	$1{,}83*10^7$	41165
Ratio	2,8	2,91	1,81

Table 5. Scenario 3. Change of a umber of various-sizes SOs over the forecasting interval

Number of SOs	<1 cm	1 cm – 10 cm	> 10 cm
in 2012	$1{,}09*10^9$	$6{,}28*10^6$	22716
in 2062	$3{,}32*10^9$	$1{,}98*10^7$	45046
Ratio	3,05	3,15	1,98

Table 6. Scenario 4. Change of a umber of various-sizes SOs over the forecasting interval

4. Conclusions

1. Modeling results have shown that in the future the main source of formation of new SD will be mutual collisions.
2. Modeling results, obtained with using the SDP model, well agree with the results of modeling by foreign models.
3. Depending on undertaken measures, in 50 years the number of large-size SD objects can be monitored, and the further contamination can be prevented.
4. The population of small-size objects will grow irrespective of undertaken measures. It will be possible to monitor the rate of this growth only.

5. REFERENCES

1. Stability of the Future LEO Environment, IADC-12-08, Rev. 1 January 2013
2. A.I. Nazarenko, I.V. Usovik. Space debris environment modeling with allowance for mutual collisions of objects larger than 1 cm in size , 6th European Conference on Space Debris, 2013
3. J.-C. Liou et al. Stability of the Future LEO Environment – An IADC Comparison Study, paper for review regarding proposed submission to JASR, 20130319.pdf
4. A.I. Nazarenko, "Space debris status for 200 years ahead & the Kessler effect», 29-th IADC 2011
5. A.I. Nazarenko, «Estimation of the contribution of the effect of collisions of objects larger than 1 cm in size», 30-th IADC 2012.
6. Technical report on space debris, UN New York, 1999.
7. A.I. Nazarenko. The solution of Applied Problems Using the Space Debris Prediction and Analysis Model. Chapter 4. *Space Debris. Hazard Evaluation and Mitigation.* Edited by Nickolay N. Smirnov. Taylor & Francis Inc. 2002.
8. GOST R 25645.167-2005 "Space environment (natural and artificial). Model of time-space distribution of SD spatial density and flux in LEO", GOSSTANDART, RUSSIA, Moscow, 2005.
9. ODQN, Volume 17, Issue 1, January 2013
10. http://www.space-track.org
11. A.I. Nazarenko. Application of average contamination sources for the prediction of space debris environment. *AAS/AIAA Space Flight Mechanics Meeting. Monterey*, CA, February 1998. AAS 98-161.
12. A.I. Nazarenko. Modeling Technogenous Contamination of the Near-Earth Space. *Solar System Research*. Vol. 36, No. 6, 2002, pp. 513-521