THE “IADC SPACE DEBRIS MITIGATION GUIDELINES” AND SUPPORTING DOCUMENTS

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(The invited presentation is on behalf of the IADC WG 4)

ABSTRACT

The "IADC Space Debris Mitigation Guidelines" (hereafter – the “IADC Guidelines”) were worked out in 2002 by the Working Group 4 (WG4) of the Inter-Agency Space Debris Coordination Committee (IADC) as the first international regulatory document that is specialized in field of space debris mitigation and is based on consensus among the IADC members. In February 2003 the IADC had presented the “IADC Guidelines” as the proposals on debris mitigation at the fortieth session of the Scientific and Technical Subcommittee (STSC) of the Committee on the Peaceful Uses of Outer Space of the United Nations (UN COPUOS).

In 2004 the IADC Working Group 4 prepared the “Support to IADC Space Debris Mitigation Guidelines” (hereafter – the “Support to Guidelines”). The “Support to Guidelines” was developed for use of all space vehicles developers and operators in their efforts on space debris mitigation. The work is directed to increasing the safety of future space explorations.

The article is aimed to consider the role and meaning above mentioned documents in future space activity, some technical features of their recommendations, the ways of their updating to be acceptable for all space faring parties and the most debatable points in development of this documents.

INTRODUCTION

Space activity is an essential part of the mankind activity in its aspiration to technical progress and prosperity of social community. Now space has come in daily life of each family. Space has proven its potential to promote global cooperation and healthy competition. Just now the multinational crew inhabits the International Space Station, a number of satellites are actively managed for the global economy benefit of human society.

But the general human’s support for space is not commensurate with the benefits that are derived from space activities. Many thousands of launches had taken place since the first space flight of Russian “Sputnik” in October, 1957. Each of space missions adds new long lived objects to near Earth orbits. Some of launchers and satellites had been broken by explosions most of which occurred for the unforeseen reasons thus forming space debris population. Current risk of damage to space systems, as well as to people and objects on the Earth is not considerable but this risk is being increased consistently from year to year. The first officially registered space objects collision occurred on July 24, 1996. French satellite Cerise (50 kg mass, 670 km orbit) collided with an Ariane launcher fragment. Dangerous approaches of large fragments to the International Space Station occur repeatedly, creating a threat to the crew. Some unforeseen depressurization events took place for the spacecraft at geostationary orbit (GEO).

Space faring nations are concerned about increasing danger of space debris. Mitigation measures are needed to preserve the near-Earth space environment for future generations. Fundamental principles followed for debris mitigation are essentially the same and include the following activity:

- limitation of debris released during normal operations;
- minimisation of the potential for on-orbit break-ups & collisions;
- removal of non-operational objects from populated regions.

In 2002 the Working Group 4 of the Inter-Agency Space Debris Coordination Committee worked out the "IADC Space Debris Mitigation Guidelines" that is the first international regulatory document specialized in field of space debris mitigation. Two years later the Working Group 4 prepared the “Support to the IADC Space Debris Mitigation Guidelines” (the Action Leader - Dr Akira Kato, Japan). In the last document there were specified:

- purpose or rationale for each “IADC Guidelines” recommendation;
- practices or how to cope with the said recommendations, applicable methods and justification of the numerical values;
- tailoring guide;
- feasibility, definition of parameters, technical information, applicable references and examples.

The “Support to Guidelines” includes the same issues as the “IADC Guidelines”: (1) preventing on-orbit break-ups, (2) removing spacecraft and orbital stages, and (3) limiting the released objects. Every item was analyzed carefully in view of the best practice in this field of activity.

In 2003 the "IADC Guidelines" were presented to the STSC as IADC proposals on debris mitigation (Ref.: A/AC.105/c.1/l.260). The STSC at its 42-nd session

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make the decision to work out a Subcommittee space debris mitigation document taking into account all the comments prepared by STSC Member States. The work is under development. All the participants understand their responsibility before future generations in achieving the results on the basis of consensus.

“IADC GUIDELINES” AS THE FIRST REGULATORY DOCUMENT IN DEBRIS MITIGATION

There is no codified set of “rules of the road” for space operations now. In 2001 the Sixth International Workshop held in Seville, Spain1), stated the need of developing so-called “Rules of the space roads” for space traffic management. Potential “Rules of the space roads” fall into a few general categories. These could include the following:

- Right of way rules (e.g., does the first satellite in a particular orbital regime have priority? Does gross mass or fuel capacity affect rights of way?)
- Zoning rules (e.g., should some types of space activities be restricted from certain orbital regimes?)
- Communication rules (e.g., should operators of a GEO satellite passing through another satellite’s orbital location be required to communicate with the operators of the other satellites?)
- Environmental rules (e.g., rules intended to reduce the creation of orbital debris)

The "IADC Guidelines” contains all of four distinctive attributes of the said general categories. These features of the "IADC Guidelines" are illustrated below.

Right of way rules

The main feature of the “IADC Guidelines” is that the document does not create the preconditions for assigning priorities by anyone attribute such as national or organisation belonging, mission, mass, fuel capacity, etc. Two principles - of mission safety and ecological cleanliness - are used as the main for all space vehicles at all phases of their functioning: launch , mission, disposal. The rights of way rules are shown most clearly by consideration of the traffic regulation at a threat of mutual collisions. In the item 5.4 “Prevention of On-Orbit Collisions” of the “IADC Guidelines” there were said:

*“In developing the design and mission profile of a space system, a program or project should estimate and limit the probability of accidental collision with known objects during the system's orbital lifetime. If reliable orbital data is available, avoidance manoeuvres for spacecraft and co-ordination of launch windows may be considered if the collision risk is not considered negligible.”**

That is, the measures on minimisation of risk of collisions should be implemented from the initial stage of the project and if necessary they will be co-ordinated with the designers or operators of parallel systems. The consensus is supposed to be achieved in all disputable cases the same as it had been achieved by all the IADC members under development of the “IADC Guidelines”.

Zoning rules

In the item 3.3 “Orbits and Protected Regions” of the “IADC Guidelines” there were said:

“Protected regions — Any activity that takes place in outer space should be performed while recognising the unique nature of the following regions, A and B, of outer space (see Fig. 1), to ensure their future safe and sustainable use. These regions shall be protected regions with regard to the generation of space debris.

1) Region A, Low Earth Orbit (LEO) Region– spherical with an altitude (Z) less than 2,000 km;

2) Region B, the Geosynchronous Region - a segment of the spherical shell with an altitude ZGEO – 200 km < Z < ZGEO – 200 km, (Z GEO = 35,786 km).

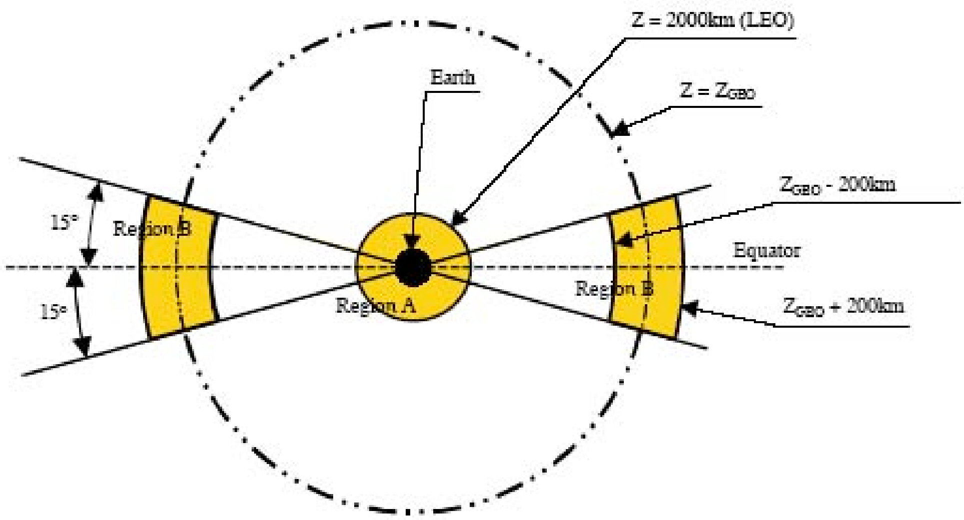

Figure 1 - Protected regions”

Communication rules

In the quoted paragraph 5.4 there are the words: "If reliable orbital data is available ". It means the existence of regular procedures of informational exchange between all the organisations which take part in observation and cataloguing of space objects. Just now this work is being organised in frame of the IADC activities. Subsequently the procedures will be formalised on the basis of achieved experience.

In addition to item 5.4 communication rules were included in the item 5.3.2 "Objects Passing Through the LEO Region":

"If a space system is to be disposed of by re-entry into the atmosphere, debris that survives to reach the surface of the Earth should not pose an undue risk to people or property. This may be accomplished by limiting the amount of surviving debris or confining the debris to uninhabited regions, such as broad ocean areas.

In the case of a controlled re-entry of a space system, the operator of the system should inform the relevant air traffic and maritime traffic authorities of the re-entry time and trajectory and the associated ground area."

The document assumes communication not only between the participants of space activity but also centre to centre management's of space flight and movement of various types of transport (see the item 4 of the Workshop major findings).

Environmental rules

As to these roles, they make the basic content of the "IADC Guidelines". The items 5-7 of the Workshop major findings are confirmed by the appropriate rules of this document.

The "IADC Guidelines" is not a static document. As it was stated: *"These guidelines may be updated as new information becomes available regarding space activities and their influence on the space environment"*. The document itself and supporting documentation should be supposed as living documents, always subject of revision and updating on the basis of an international practice of space activity.

TECHNICAL REQUIREMENTS OF THE "IADC GUIDELINES"

The "IADC Guidelines" is a document of a technical nature that covers the overall environmental impact of missions with a focus on the following:

- "IADC Guidelines" determine the basic terms and concepts in the sphere of space ecology, namely:
- Space Systems (Space object, Spacecraft, Launch vehicle, Launch vehicle orbital stages);
- Orbits and Protected Regions (Equatorial radius of the Earth, Protected regions, Geostationary Earth Orbit, Geostationary Transfer Orbit);
- Mitigation Measures and Related Terms (Passivation, De-orbit, Re-orbit, Break-up);
- Operational Phases (Launch phase, Mission phase, Disposal phase).

As the basic innovation there is the third operational phase – "disposal phase" that *"begins at the end of the mission phase for a space system and ends when the space system has performed the actions to reduce the hazards it poses to other space systems"*.

Disposal phase is entered as an obligatory phase of functioning for every space vehicle that inevitably will cause increase of cost again of created space vehicles at the expense of additional work on their designing, manufacturing and experimental improvement.

The peculiarities of technical view of the "IADC Guidelines" are as following:

- Systematic actions are declared into practice of organization's planning for and operation of a space system by introducing of mitigation measures into space system's life cycle.
- The mitigation measures are formulated for all protected regions and operational phases. The most considerable measures are as following:
- Minimize the potential for on-orbit break-ups resulting from stored energy - residual propellants, batteries, etc.
- The IADC formula for the spacecraft disposal above GEO orbit not to cause interference between this one with space systems still functioning in GEO region.
- The 25-years rule that limit presence of space systems in LEO region.

THE "SUPPORT TO THE "IADC GUIDE-LINES"

A great comprehensive work was done by WG4 and personally by the action leader Dr Akira Kato (JAXA) to summarize the best mitigation practices realized by all agencies – IADC members. As a result the "SUPPORT TO THE "IADC GUIDELINES" was prepared in 2004. This document specifies for each recommendation of the "IADC GUIDELINES" the following points:

- Purpose: rationale for the Guidelines.
- Practices: recommendations on how to cope with the Guidelines, applicable methods, and justification of the numerical values.
- Tailoring guide for each of the Guidelines.
- Feasibility.
- Definition of parameters and technical information.
- Applicable references, and examples.

The "SUPPORT TO THE IADC GUIDELINES" may serve as Handbook in space debris mitigation practice for designers of space systems and operators when space systems are functioning at the orbits. The work should increase the safety of future space explorations.

Some examples of explanations placed into "Support to IADC Space Debris Mitigation Guidelines" are listed below. First of all the IADC recommendation is to ensure that the lifetime after disposal will not exceed 25 years. IADC Working Group 2 studied the effect of de-orbiting in LEO and the result is shown below. It is the debris (with sizes greater than 1 cm) population evolution that was calculated as average number of the four well-known models: Evolve , IDES, DELTA, and SDM.

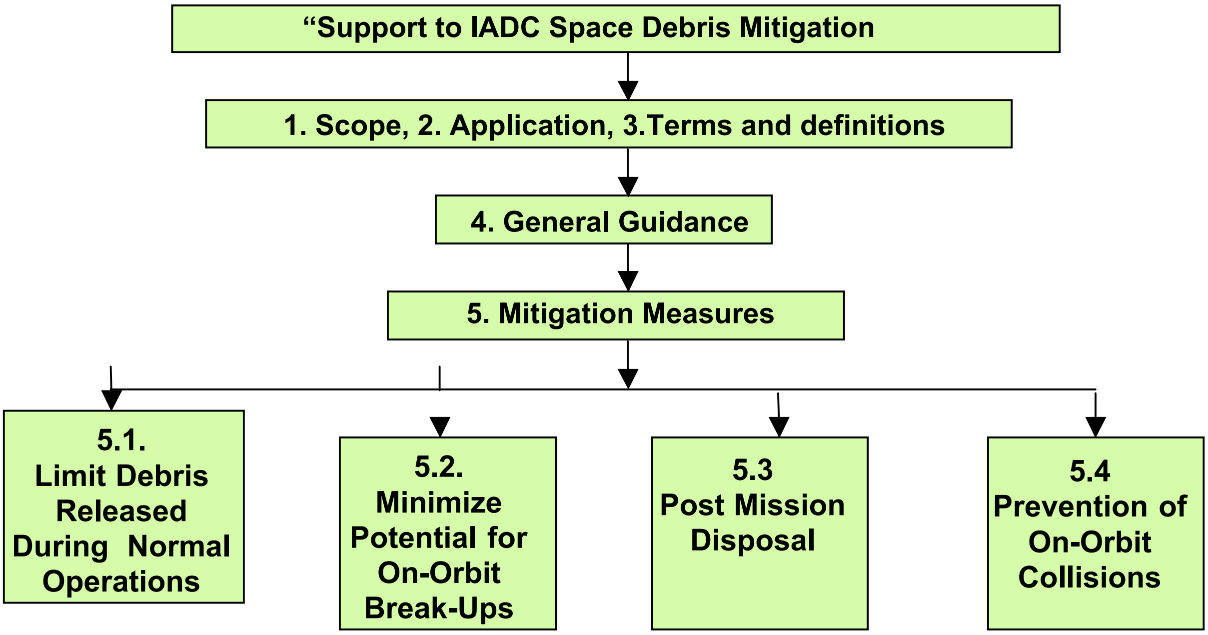

Figure 2. General content of the "Support to IADC Space Debris Mitigation Guidelines"

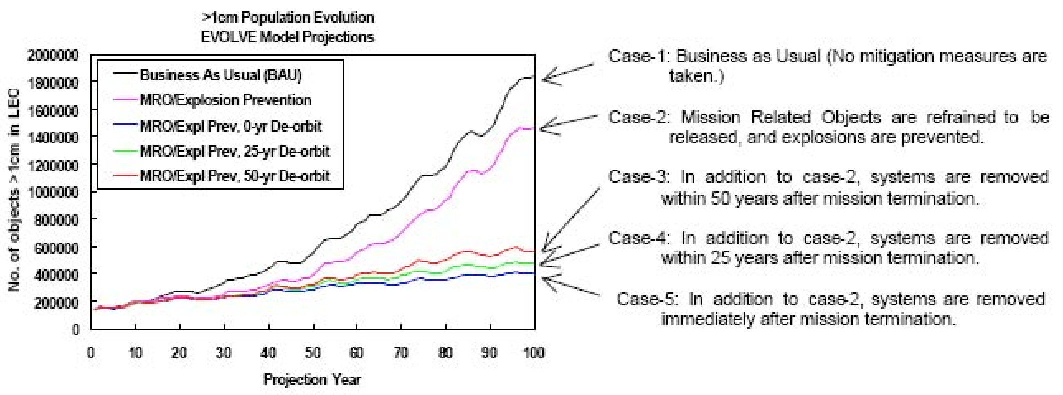

Figure 5.3.2-1 Debris (> 1cm) Average Population Evolution from Evolve

Figure 3. Debris Population Evolution

Initial Altitude	Perigee Altitude Decrease	Final perigee Altitude	Delta Velocity	Mass Fraction (Propellant / Dry Mass)
800 km	70 km	730 km	18 m/s	0.8%
1,000 km	370 km	630 km	88 m/s	4.3 %
1,500 km	965 km	535 km	236 m/s	11 %
2,000 km	1505 km	495 km	349 m/s	17 %

Figure 4. Practice of re-orbiting at end of life.

The accepted designations are as follows: MRO: Mission Related Objects are refrained to released, Expl Prev: Explosions and other break-up events are prevented, N-yr De-orbit: S/C & Rocket Bodies are removed within N years from orbit.
The next example concerns practice of re-orbiting at end of life. In the table below there are presented the calculated amount of the required propellant for lifetime reduction within 25 years for different types of inter-orbital transfers (I sp = 200 sec, A/m = 0.05). For orbits above 1400 km, less energy is required to re-orbit above 2000 km than to manoeuvre into a disposal orbit with a lifetime of 25 years or less.
More than 4,300 missions to Earth orbit (more than 5,000 tons in mass) have been accomplished since 1957. More than 50 large objects (system level objects) typically fall back to Earth every year. The re-entries of Cosmos 954 on Canadian territory in January 1978 and Skylab in the oceans and on Australia in July 1979 are well-known. Large objects that have re-entered since the 1980's are listed in the following table. Typical parameters to assess re-entry safety are casualty area and the casualty expectation (Ec). An allowable Ec is not currently recommended in the IADC Guidelines, while NASA Safety Standard 1740.14[3] , U.S. Government Orbital Debris Mitigation Standard Practices[4] , and NASDA Space Debris Mitigation Standard (NASDA-STD18A)[5] limit the value of Ec to less than 10-4 [persons per event].

Name	Nationality	Mass [kg]	Date of Decay	Mode
Salyut 6/Cosmos 1267	Russia	35,000	29-Jul-82	Controlled Re-entry
Cosmos 1443	Russia	15,000	19-Sep-83	Controlled Re-entry
Apollo 9 CSM BP-16	USA	16,700	10-Jul-85	Natural Re-entry
Apollo 8 CSM BP-26	USA	16,700	8-Jul-89	Natural Re-entry
Salyut 7/Cosmos 1686	Russia	40,000	7-Feb-91	Natural Re-entry
Compton GRO	USA	14,910	4-Jun-00	Controlled Re-entry
Mir	Russia	120,000	23-Mar-01	Controlled Re-entry

Figure 5. Large objects that have re-entered since the 1980's.

THE WAYS OF FUTURE DEVELOPMENT OF THE "IADC GUIDELINES"

In February, 2003 at the 40-th session of Scientific and Technical Subcommittee the IADC had presented the "IADC Guidelines" to the Subcommittee as the IADC proposals on space debris mitigation.

Spacecraft with nuclear power sources

In February, 2004 at the 41-st session of Subcommittee the Member States formulated remarks to IADC proposals on space debris mitigation. The remarks was guided mainly by aspiration to ensure the conformity of the new document to the international space law and promote safety of space flights. So, possible ways of future development of the "IADC Guidelines" are as follows.

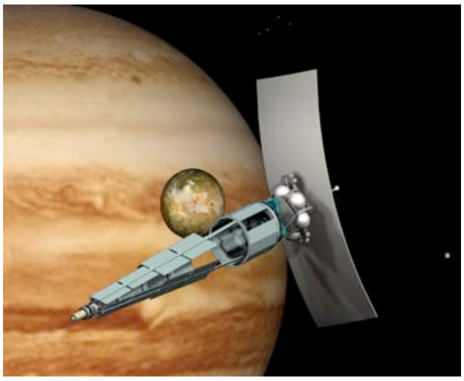

Figure 6. S/C with NPS.

The requirements of the proposed by the "IADC Guidelines" contradict to the "Principles Relevant to the Use of Nuclear Power Sources (NPS) in Outer Space" accepted December 3, 1986 on US General Assembly. First of all it concerns "Guidelines" requirements about forbidding of spacecraft fragmentation and also to spacecraft disposal in according with " 25 years rule" at the end of mission.

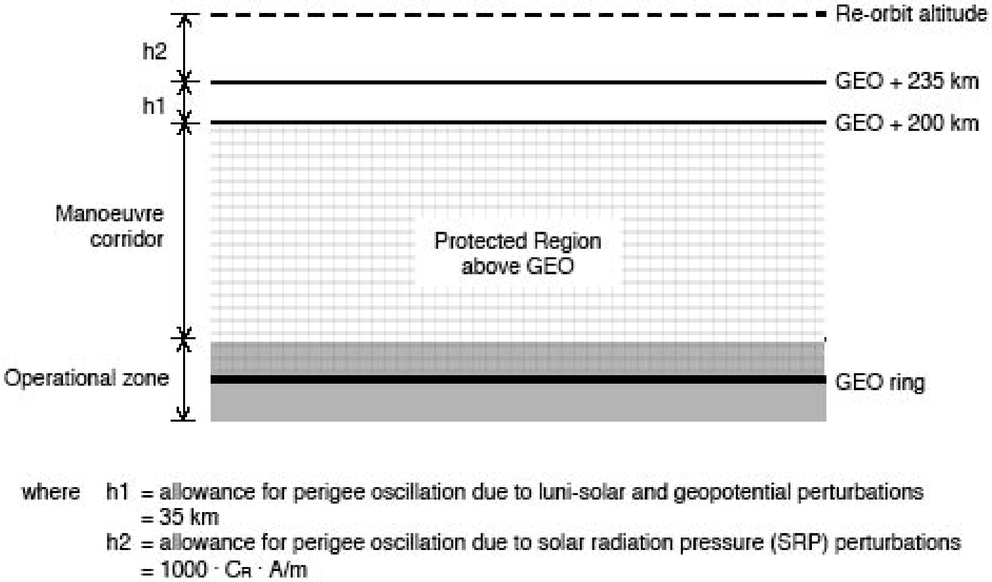

Figure 7. GEO Disposal Scheme

GEO POST MISSION DISPOSAL

"IADC Guidelines" recommends minimum increase in perigee altitude at the end of re-orbiting, which takes into account all orbital perturbations, in according with the formula:

235km+(l,000*CR*A/m), where

C_R : solar radiation pressure coefficient (typical values arc between 1 and 2);

A/m : aspect area to dry mass ratio [m2 / kg];

235 km: sum of the upper altitude of the GEO protected region (200 km) and the maximum descent of a re-orbited space system owing to luni-solar and geopotential perturbations (35 km).

In recent years, the influence of the shape of the disposal orbit following a manoeuvre has been brought into question. In particular, the affect of the initial orbit parameters on the natural evolution of the disposal orbit, and whether this evolution will result in the re-orbited object entering the protected region above GEO. The undertaken study shows that an additional parameter should be introduced to the "Guidelines": the recommended orbit should have an eccentricity ≤ 0.005.

SMALL SATELLITES

The new class of satellites is under development: –nano-, pico- and femto- satellites. These satellites are not equipped with on-board engine and can not be disposed to 25 years orbits at the end of mission. After the end of mission nano-, pico- and femto- satellites turn into invisible space debris population. For example there The small sized space debris population is presented at figure 8. The blue data were calculated on the basis of space debris model "ORDEM-96". The violet data were observed by Cobra Dane Radar. Both data were normalized at the point "d = 9-10 cm". It can be seen that at point "4-5 cm" the debris flux measured by Radar is ~30 times less than the flux predicted by the theory. So, the small sized space debris population can not be predicted by the radar measurements with high accuracy and it is expedient to pay attention to the above mentioned class of satellites and to specify opportunities of their usage from point of view of debris mitigation.

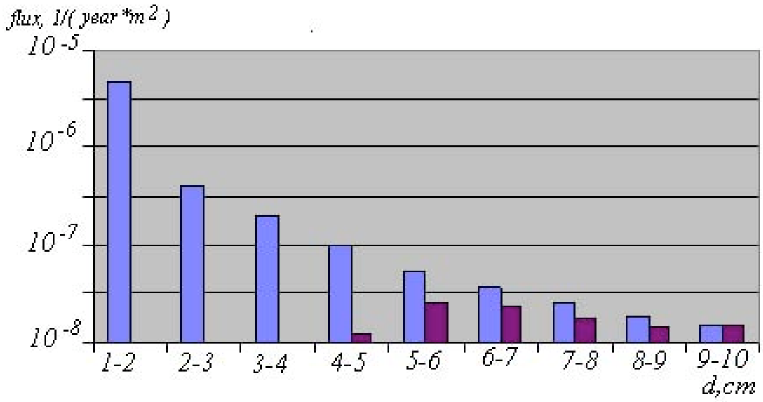

Figure 8. Small Sized Space debris population

SUMMARY

The "IADC Guidelines" is developed via consensus within the IADC members for planning space missions and designing of space vehicles in order to minimise or eliminate generation of debris during space operations.

The "IADC Guidelines" is the first regulatory international document that determines the peculiarities of future space traffic management or so called "Rules of the space roads".

The technical content of the "IADC Guidelines" will be used as the basis for development of another space debris mitigation documents in the Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space, International Organization for Standardization etc.

The "SUPPORT TO THE IADC GUIDELINES" summarizes the best practices in field of space debris mitigation that realized by all space-faring agencies and specifies for each recommendation of the "IADC GUIDELINES" the purpose, the recommendations on how to cope with the Guidelines, tailoring guide for each of the Guidelines requirement, feasibility of requirements, definition of parameters, other technical information, applicable references, and examples.

The "IADC Guidelines" is a living document and it may be updated as new information becomes available regarding space activities and their influence on the space environment. Possible ways of "IADC Guidelines" future development are as follows:

- spacecraft with onboard nuclear power sources;
- specifying of GEO dissposal orbit parameters;
- long term presence of GTO objects in GEO region;
- additional protection of manned flight orbits;
- safety usage of nano-, pico- and femto- satellites with point of view of debris mitigation.

REFERENCES

1. "International Space Cooperation: Addressing Challenges of the New Millennium" - American Institute of Aeronautics and Astronautics; Report of an AIAA UN/OOSA CEAS IAA Workshop; Seville, Spain, March, 2001.
2. "IADC space debris mitigation guidelines", UN COPUOS 40-th session, Vienna, 17-28 February 2003, Space Debris, A/AC.105/C.1/L.260.
3. NASA Safety Standard 1740.14
4. US Government Orbital Debris Mitigation Standard Practices, December 2000
5. NASDA-STD-18: NASDA Space Debris Mitigation Standard