# THE ESA SPACE DEBRIS MITIGATION HANDBOOK

Dietrich Rex* , Heiner Klinkrad **, Jörg Bendisch *
* Technical University Braunschweig, IFR
** ESA/ESOC, Darmstadt

## 1. THE ROLE OF THE HANDBOOK

The purpose of the Handbook is to provide technical information on the space debris situation and guidance on how to avoid space debris in future spacecraft design and mission planning. It is the intention that this Handbook can be used for these purposes within ESA and in the European Industry as well as in space research planning.
In itself, the Handbook has no regulatory character. However if regulations were to be introduced in Europe by other documents, reference could be made to suitable paragraphs of the Handbook, which by such process would become binding. An approach of this kind which has already started, is the drafting of the European Cooperation for Space Standardization, ECSS, where initial paragraphs on space debris are contained and later can include reference to the Handbook.

## 2. DRAFTING PHILOSOPHY AND STRUCTURE

The Handbook is printed out as the product of an underlying software. The software controls the text as well as all graphical material, such as diagrams, sketches, tables etc. By making changes to the parameters of the underlying software, the handbook can easily be updated according to technology and environment changes. The underlying software calls upon a set of computer codes, such as MASTER, CHAINEE etc., and produces the graphs in the Handbook (or updates thereof) in an automatic editing manner. A lose-leaf book adition is envisaged in order to update the copies of all users.

The Handbook will have the following main chapters:

**Outline of ESA´s Space Debris Mitigation Handbook**

0. Definition of terms, abrevations
1. Definition of the scope of the Space Debris Mitigation Guidelines
2. Description of the current environment and resulting collision fluxes
3. Impact risk assessment
4. Analysis of future traffic scenarios
5. Analysis of mitigation measures
6. Controlled re-entries
7. Uncontrolled re-entries
8. On orbit collision avoidance (for LEO)
9. On-orbit shielding technology
10. Spacecraft passivation at end-of-life
11. Launcher passivation and de-orbit strategies

In the following parts of this paper, some selected topics of the Handbook will be discussed.

## 3 DESCRIPTION OF THE CURRENT ENVIRONMENT

The current environment is reflected in the Handbook as a result of the MASTER model. When, in due course, the MASTER model will be updated by including new debris sources etc, then the Handbook can immediately be matched to the new situation.
Fig. 1 and Fig. 2 show examples of graphs provided.

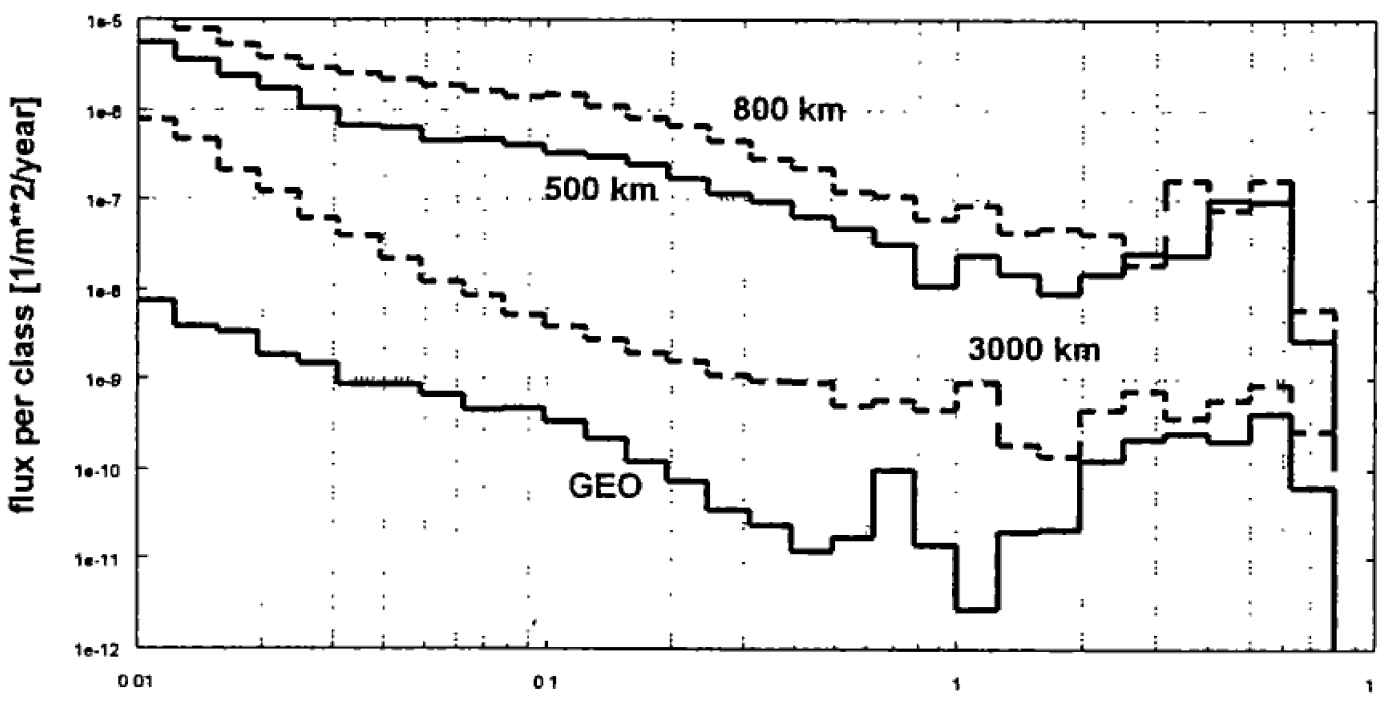


Figure 1. Size distribution of the debris flux at various altitudes. (Target object on circular orbits, i = 30°, i = 0° on GEO)

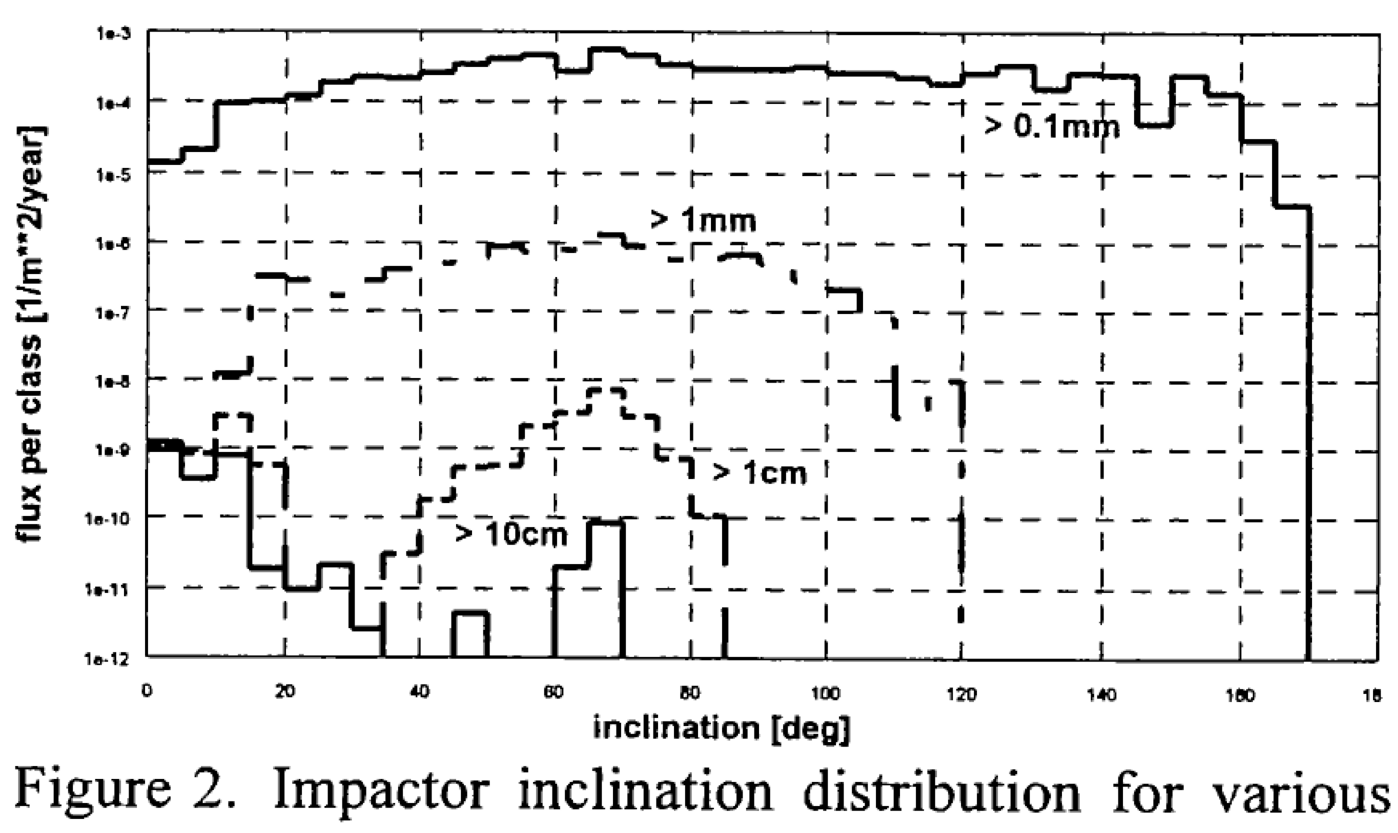


Figure 2. Impactor inclination distribution for various impactor sizes.

## 4 ANALYSIS OF FUTURE TRAFFIC SCENARIOS

### 4.1 Deployment of Satellite Constellations

The upcoming deployment of various satellite constellations will add more than 10 % to the trackable population, it will, however, triple the number of active satellites. So it is worth while to study its influences. Since all satellites of a constellation have the same altitude, the object density in a certain shell is considerably increased, Fig. 3. Collisions among the satellites of a constellation are eliminated by coordinated orbital control, the influence on the background must be included in future analyses.

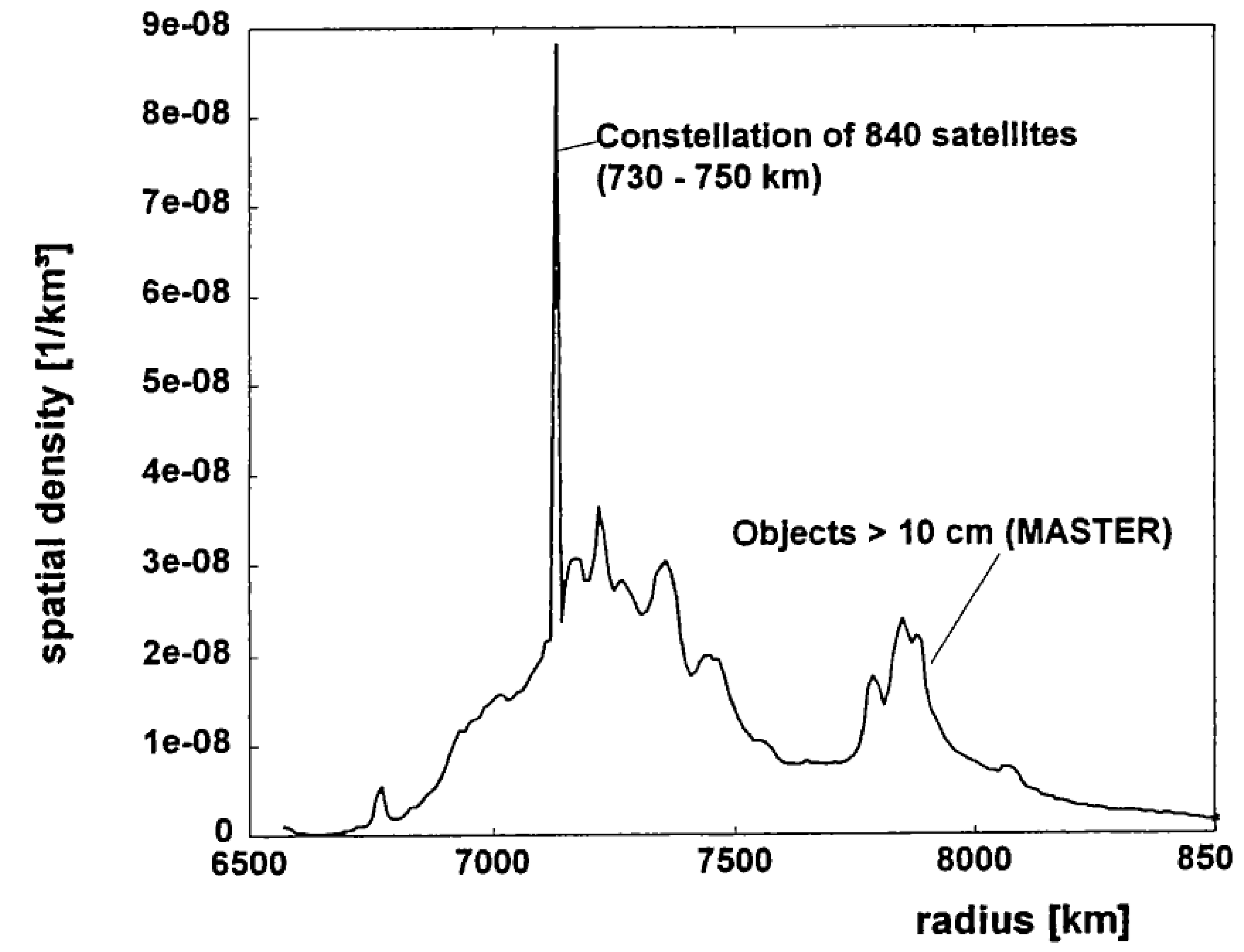


Figure 3. Altitude distribution of trackable objects with the addition of one potential constellation

### 4.2 Long Term Evolution with on Orbit Collisions

The long term evolution is analysed with the code CHAINEE. It is well known, that if we continue space flight as in the past, then the number of debris objects from collisions becomes larger then all other object numbers over long times. Fig. 4 shows this evolution. The lowest curve is the continuation of the linear increase of launched objects and explosion debris, which was observed in the past. The other two curves are averages of multiple Monte-Carlo runs, with the best collision models avaiable. Of course, such average simulation does not and cannot represent what really will be the evolution, the increase may be faster and slower. It is, howerver, indicative of the possible future. Here, after 100 years, the present population (lager than 1 cm) will have risen by a factor of 4, about half of which is due to collisions. after 200 years the population lager than 1 cm would be more than 10 times the present population, nearly 70% of it then is due to collisions. The role of feedback collisions ( in which collisional debris triggers new collisions) only comes

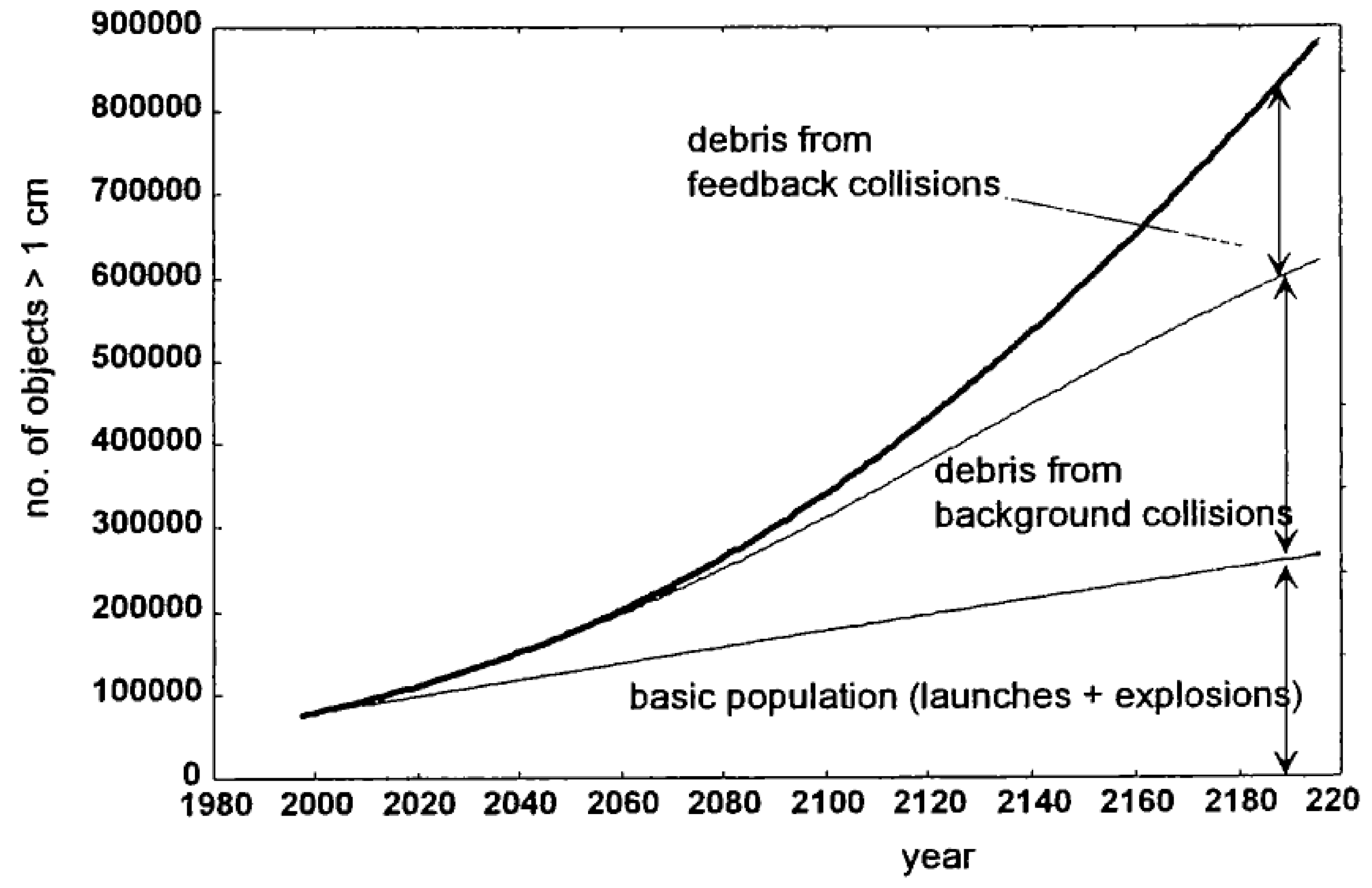


Figure 4. The long term orbital debris evolution as predicted by CHAINEE (averaged calculation).

into the picture after about 100 years. So, mitigation measures being taken timely, we will probably - and hopefully - never see collisional feedback cascading to happen.

Of course, in the ESA handbook this result gives rise to the recommendation of de-orbiting of launched payloads and rocket upper stages, as will be discussed in section 5.

## 5. ANALYSIS OF MITIGATION MEASURES

### 5.1 The Effects of Upper Stages/Payloads Passivation and of De-orbiting /Lifetime reduction

In the Handbook, venting of residual propellants from upper stages and payloads is considered to begin generally in the year 2005.

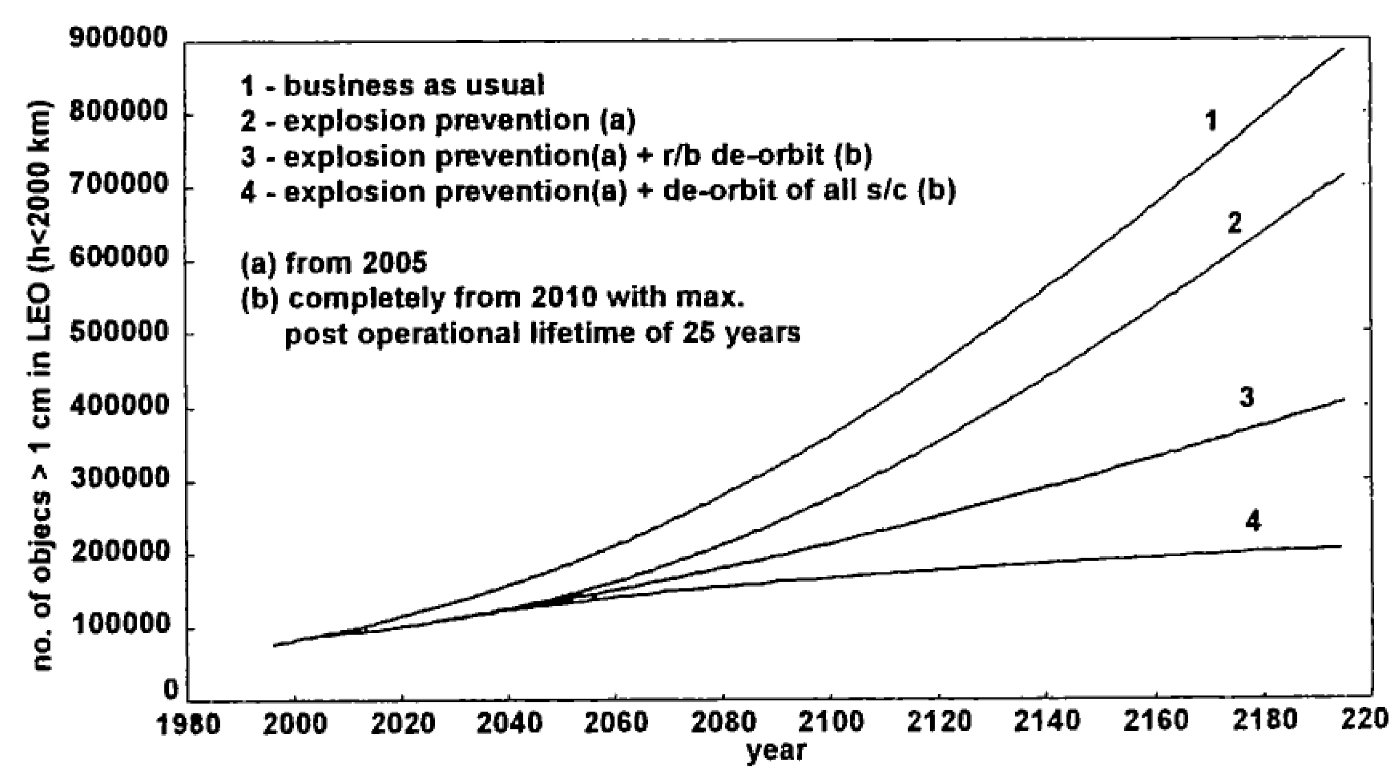


Figure 5. The effectiveness of various mitigation measures as assessed by CHAINEE.

In Fig. 5, instead of direct de-orbiting of objects to the ground (rocket upper stages after payload injection, payloads after their active service) the measure to limit all orbital lifetimes to 25 years has been analyzed. Space objects with a natural orbital lifetime shorter that limit would then not require any action.

Indeed, from our calculations, a lifetime limit of 25 years is justified with respect to its effectiveness to limit the population and with respect to cost. However, in such an uncontrolled re-entry, the risk to the ground posed by not-burned-up residuals must be considered.

5.2 The use of Disposal Orbits

The handbook will not advise to put spacecraft into disposal orbits with one exception: the gravegard orbit 300 km above GEO to store spent geostationary satellites, Fig. 6. This Storage orbit for GEO is presently

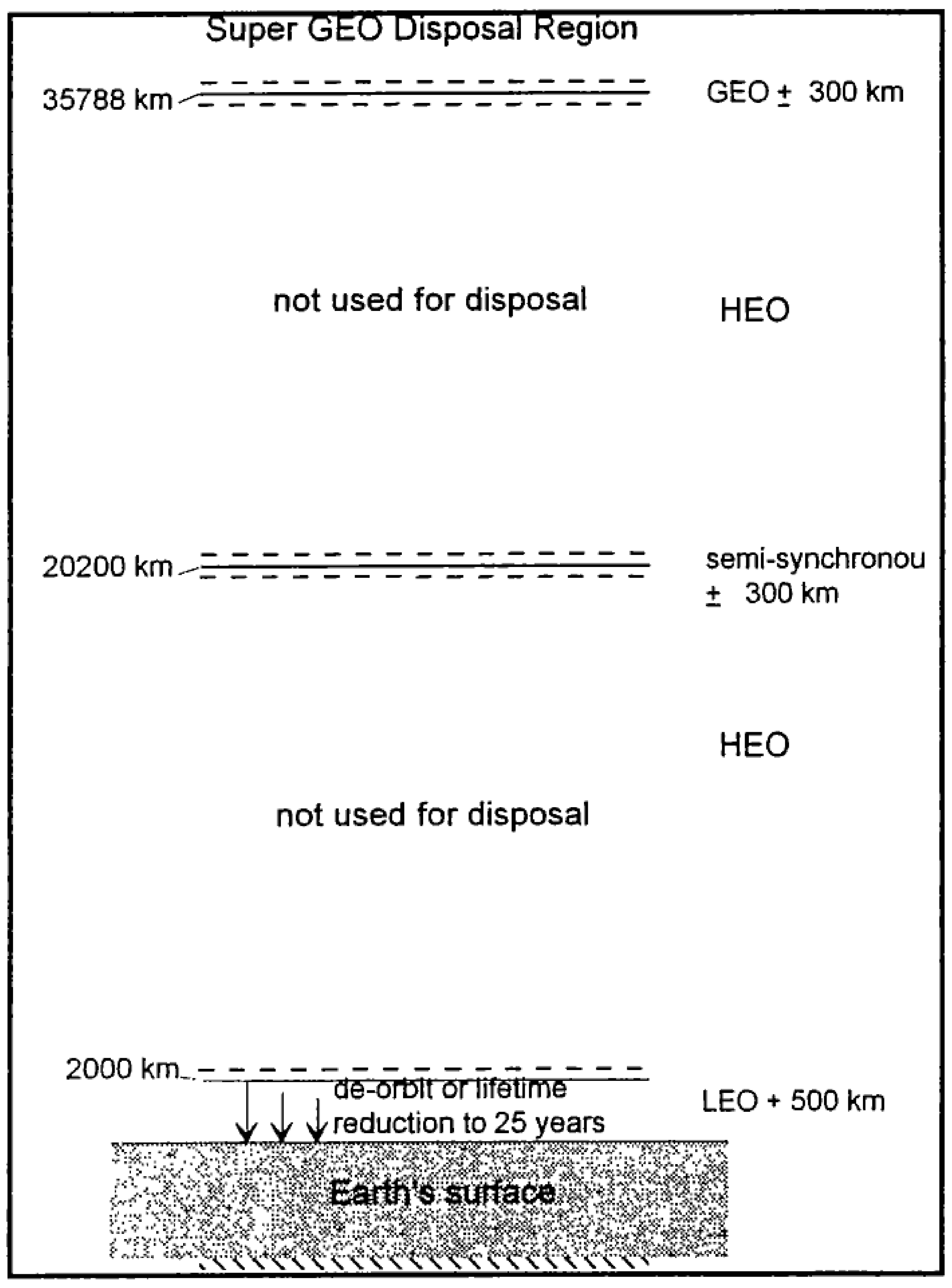


Figure 6. Usage of orbital regions

the only posibility to dispose of GEO satellites, since both, Earth escape and reentry to the Earth's atmosphere from GEO are too big technical and economic burdens. This storage orbit is safe against the possibility, that the stored objects come back to GEO by orbital perturbations, it is not safe for GEO, however, in case of debris generation by collisions. Therefore the storage 300 km above GEO is justified as an intermediate step for many decades, after which hopefully, a final solution will become possible by new technology.

At the higher edge of the LEO region, i.e. between 1000 and 2000 km circular altitude, the technical and economic burden of de-orbiting an object to the ground or to shorten the lifetime to 25 years is more severe than in the lower LEO region. This has given rise to ideas of using altitudes higher than 2500 km for disposal of satellites from e.g. 1500 km altitude circular

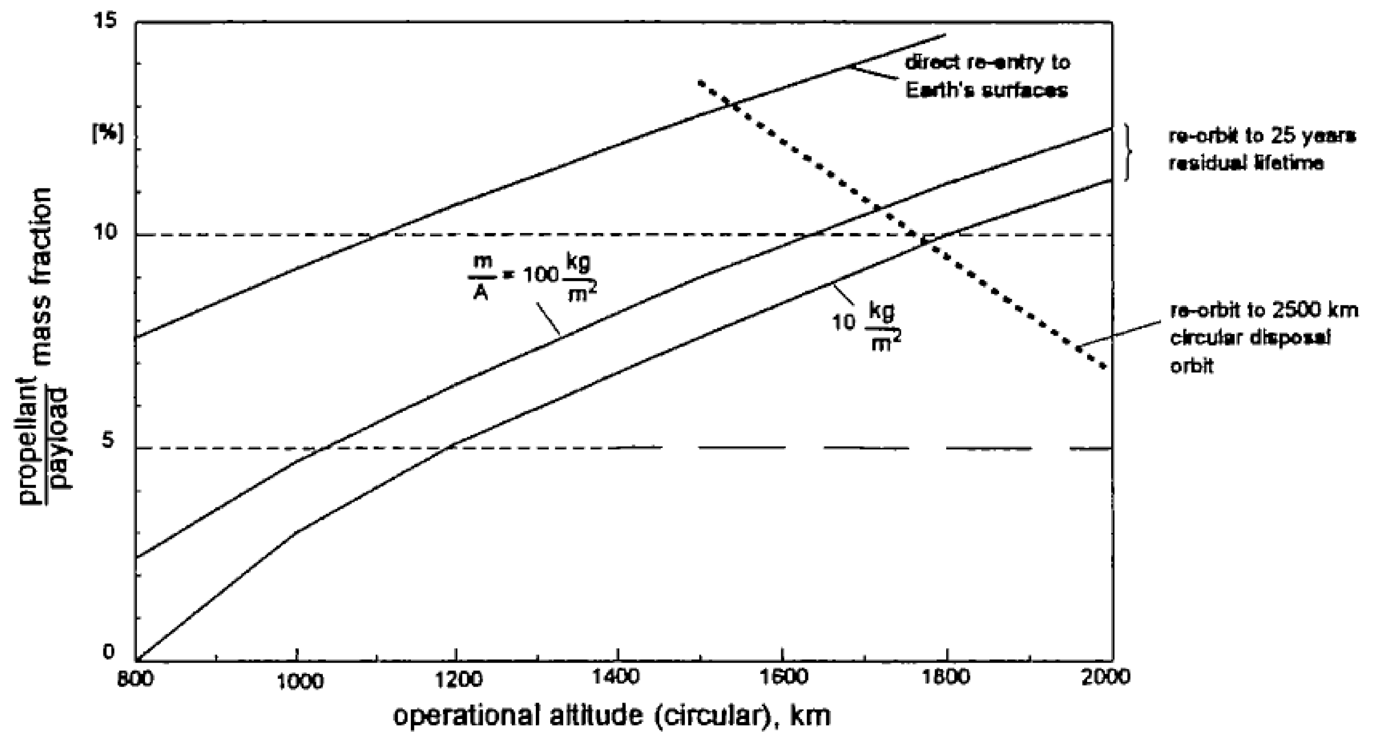


Figure 7. Propellant mass faction for various disposal-manoeuvers form higher circular LEO orbits. (Specific impulse 2800 m/s, medium solar activity).

mission orbits. The cost of this orbit-raising manoeuvre in terms of propellant/payload mass fraction is shown in Fig. 7, in comparison to the de-orbit manoeuvres. There is a break-even point between direct re-entry to ground and lifting to 2500 km circular storage orbit around 1500 km mission orbit. So, for circular mission orbits between 1500 km and 2000 km, lifting to 2500 km would be cheaper. But if lifetime reduction to 25 years is considered, then the cost advantage of the lifting manoevre to 2500 km is too small to justify such a storage orbit. Of course, uncontrolled re-entry after 25 years must be proven to be safe with regard to possible impacts on the ground.

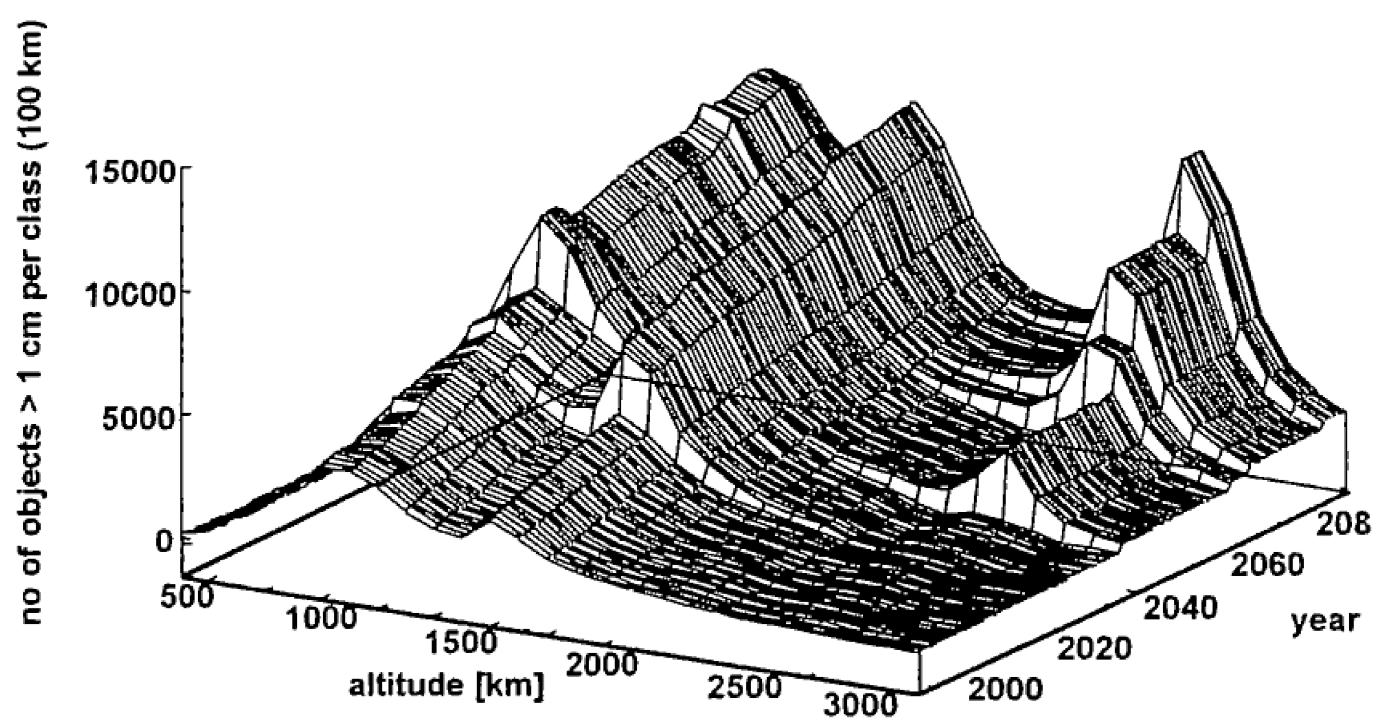


Figure 8. Potential build-up of debris density at 2500 km due to long term disposal of 20 objects per year and stochastic collision wents.

In any case, the assignment of the orbital region above 2500 km to the disposal of space objects would tend to create new problems. To save cost in the storage manoeuvre, all objects would be stored more or less at the lower limit of the disposal region, i.e. at 2500 km, not higher. The long-term accumulation of objects there might eventually lead to colliosions in the storage region, the fragments of which would be scattered back into LEO, see Fig. 8. Also, how can we know whether perhaps a new utilization of 2500 km circular orbits will emerge in the future, as was the case with 12 hour-orbits a decade ago?

Also, such a pseudo-solution of the overcrowding problem at 15oo km altitude would hamper the search for new technical procedures. The development of, e.g. electromagnetic plasma thrusters and electrodynamic tethers for de-orbiting should be promoted rather than discouraged. For the Handbook, it seems to be premature to recommend a certain procedure for spent objects in higher LEO regions.

# Chapter 11

# Policy and Legal Issues