NASDA DEBRIS MITIGATION STANDARD AND NEXT PLAN

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ABSTRACT

After the establishment of "Space Debris Mitigation Standard", our activities for next steps will be (a)establishment of a system to assess mitigation plan of each program, (b)identification of rest of issues and making plan to solve them.
In NASDA, each Program Office and Safety Management Department will perform to produce the draft mitigation plan which will be reviewed by Safety Review Committee.
To provide technical data to promote understanding of the sprits of STD and give the guideline for tailoring of each requirement, a handbook is being produced by Reliability Assurance Department.
The Long Term Debris Mitigation Plan for our future activities being discussed in NASDA is introduced here.

1. OUTLINE OF STD-18

1.1 Concept

"NASDA Space Debris Mitigation Standards" requires mitigation measures in order to limit the orbital debris generated during launch, on-orbit operation, and after the end of the mission. (Ref. 1)
The standard is based on the following concepts;
(1) The worst cause of orbital environment deterioration is on-orbit breakups caused by collision with an large object, accidental explosion, and intentional destruction.
(2) To preserve the orbital environment is particularly important for GEO (Geosynchronous Earth Orbit) because natural forces can't clean up the debris.
(3) To preserve LEO (Low Earth Orbit) environment is also important because of its usefulness for various missions such as earth observation and communications.

From the above concepts, the Standard includes the following mitigation measures
(1) Passivation of the spacecraft and the upper stages after the end of the mission.
(2) Reorbitting of the spacecraft in GEO after the end of the mission.
(3) Disposition of the objects in Geostationary Transfer Orbit (GTO) to prevent risk to GEO.
(4) Minimize the debris released during normal operation.
(5) Postmission disposal of spacecraft from LEO.

1.2 Structure

The NASDA Standard consists of general requirements provided in the context of the life-cycle phases of space system development, management requirements for organized activities both within NASDA and by contractor organizations, safety requirements for reentering systems, and detailed design guidelines for launch vehicles and spacecraft.

The STD structure is as follows.
(1) Management requirements for organized activities by both NASDA and contractors.
(2) Considerations from the requirements definition phase.
(3) Requirements for the design of space systems.
(4) Requirements for determination of flight trajectory of the launch vehicles.
(5) Requirements for the on-orbit operation of spacecraft.
(6) Requirements to properly dispose of space systems at the end of their missions.
(7) Requirements for conducting atmospheric reentry for postmission disposal.
(8) Detailed requirements for design of space systems.

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1.3 Feasibility for Compliance

All the requirements are not always feasible for every space systems. We may be able to summarize roughly the feasibility of each main measures as follows.

1.3.1 Prevention of on-orbit breakups

It is relatively easy. There are not so many technical problems and not so much additional cost will be required to control accidental explosions. Of course some detail discussion might be required, how we can guarantee the operation life for batteries and bleed for example. But basically those are not critical problems. Talking about other factors of breakups, intentional destruction is strongly prohibited by our standard.

1.3.2 Post-mission disposal of GEO spacecraft

It is also not so difficult except economical factor to spent propellants for reorbit maneuver. If only all the world space user can agree with some distance, the rest of problem will be the measuring system precision errors of residual propellant measurements to guarantee the distance.

1.3.3 Post-mission disposal of LEO spacecraft

It is difficult. Some mission can't satisfy this requirement perfectly so we need some tailoring of requirement according to the characteristic of the orbit etc.

1.3.4 Post-mission disposal of upper stages on GTO

It is difficult to remove it perfectly, but only to reduce the period of interference with GEO will be relatively easy. If perigee altitude would be enough low, natural force will satisfy the requirement. Particularly the upper stage of H-II vehicle can generate thrust to decent its orbit to satisfy this requirement.

1.3.5 Minimization of operational debris

It is not so difficult, except lower fairing in case of multipayload launch.

So some requirements, which are identified to be difficult to satisfy, may need to be tailored when the STD is applied. The discussion for tailoring will be described in the section 3.

2. EVALUATION PROCEDURE

2.1 Management Organization

The Standard requests each NASDA Project Manager to prepare a Space Debris Mitigation Plan including an adequate rationale for items for which an exception is requested. This plan will be reviewed by the NASDA Safety Review Committee. The manufacturers are also requested to establish an organization to manage space debris issues and to prepare a Space Debris Mitigation Management Plan.
The STD request at least two steps of reviews during the design phases. The first review is required at Preliminary Design Review (PDR); the purpose of this assessment is to identify potential debris issues early in the program development cycle. A second review is required at Critical Design Review (CDR); this report documents changes made since the PDR report and demonstrate the resolution of debris issues raised at PDR.

2.2 Handbook and Tailoring Guide

The handbook, which explains each requirement and provides technical data and guidelines for satisfying the intent of the space debris control policy, will be prepared by the end of 1997.
One of major purposes of this handbook is to provide guidelines for tailoring.
The STD acknowledges that a plan for space debris control must be tailored for each program.
Some projects which are currently well into their development cycle may be allowed to violate some requirements, for example.
Another factor of tailoring may be the feasibility of measures discussed in previous section.

3. TAILORING FOR DISPOSAL REQ.

Most difficult requirement is Post-mission Disposal of LEO spacecraft. Tailoring guide should lead the each project to chose most adequate option.

3.1 Option Priorities

Based on the analysis for reentry survivability of typical spacecraft, the risk of ground impact can't be ignored. The priorities of the methods to remove the space systems from the useful orbit should be decided as follows.

(1) If the risk of ground impact is acceptable,
  a) As a basic rule, the space systems should be removed from the orbit by atmospheric reentry

within 25 years. (That will be called "orbit lifetime reduction.")

b) If the operation orbit is too high for effective lifetime reduction, the space systems may be reboosted into "less useful graveyard orbit".

(2) If the risk of ground impact is not acceptable,

a) As a basic rule, the space systems should be removed by controlled reentry into a safe international waters.

b) Or the space systems should be retrieved on orbit by the Space Transportation Systems, if economically possible.

c) If above measures can't be taken, the space systems should be reorbited into the graveyard region or reboosted to extend their orbit lifetime.

3.2 Conditions and assumptions

Following conditions, which are stated in STD-18, and assumption for this discussion are as follows. Justifications of these values are explained in the document for IAF congress.(Ref.2)

(1) Graveyard orbit
 (a) Low-altitude graveyard region
  above 1,700km below 19,900km
 (b) High-altitude graveyard region
  above 20,500km below 35,288km

(2) Allowable lifetime for disposal
NASDA adapt same value as NASA standards. That is 25 years until mission-terminated space systems will be removed from orbit.

(3) Available propellant for disposal maneuver
Available propellant is assumed to be 5% of the initial mass of spacecraft in this paper.
(Isp=200sec, area/mass=0.05)

Table 1 shows the idea how to select one the options very roughly.

Table 1 List of simplified measures depending on altitude

Condition	Measures, feasibility
Case 1 : Human casualties : acceptable	
Below 750km	Leave as it is, (It will reenter by natural forces within 25 years.)
Below 1,000km	Lifetime reduction within 25 years by maneuver by 5% propellant.(feasible)
From 1,000km to 1,500km	Reduce lifetime as much as possible or send to graveyard orbit (not easy)
Above 1,500km	Send to graveyard orbit above 1,700km (feasible)
Case 2 :Human casualties : not acceptable	
low enough	Controlled reentry (need study) or retrieve by STS (need budget)
higher than 750km	Send to graveyard orbit (difficult) or Reboost only to extend lifetime to more than 100 years (feasible)
higher than 1,500km	Send to graveyard orbit (feasible)

A/m = 0.05, Isp = 200sec, dm/M=5%

But the table includes the difficult area where any effective measures can't be found. We need more discussion for that.

3.3 Tailoring

3.3.1 If reentry risk is acceptable

If reentry risk is acceptable, basic requirement is lifetime reduction by pulling down the one of apses. This is very reasonable if the operation orbit is below 1000km (or 1500km) where the debris density is very high (or relatively high).

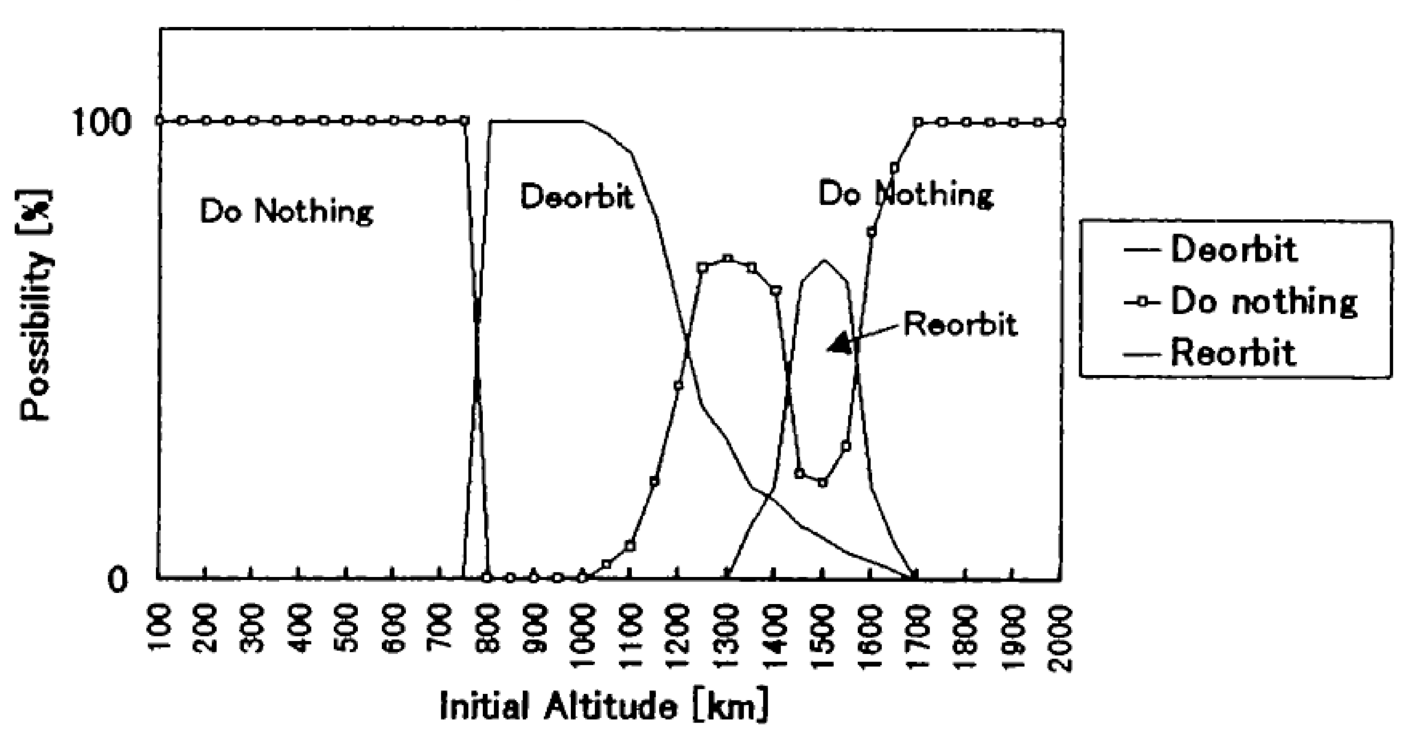
But for the operation orbit above 1700 km where lifetime reduction effect is small as far as propellant mass is limited, and debris density is not high, deorbit maneuver may not have enough meaning, rather increases the risk for space activities in most useful orbit immediately.

For the operation orbit above 1500km below 1700km where the effect for lifetime reduction is small and debris density is relatively high, to reboost into higher region may be considered to be effective to avoid immediate interference with useful orbit. However it may increase collision risk in long-term. Practical merit may be it requires less propellant than that for deorbit. The justification of reorbit will need more discussion. It will be discussed in paragraph 3.4.

So we will need the tailoring guide for these issues like the Fig. 1.

In the figure, 1500km is a lowest altitude which can be conducted reorbit to graveyard (1700km) by 5% propellant, and 1300km is a balance point that deorbit and reorbit require same amount of propellant. The third peak at 1300km means that spacecraft can be left in operation altitude because the region has not so high debris density.

Fig.1 Concept of Possibility of Option Selection



This figure doesn't have quantitative meaning.
It only show what kind of option has possibility to be applied for each altitude.

There will be following factors to be considered in selecting one of options in practical situation.

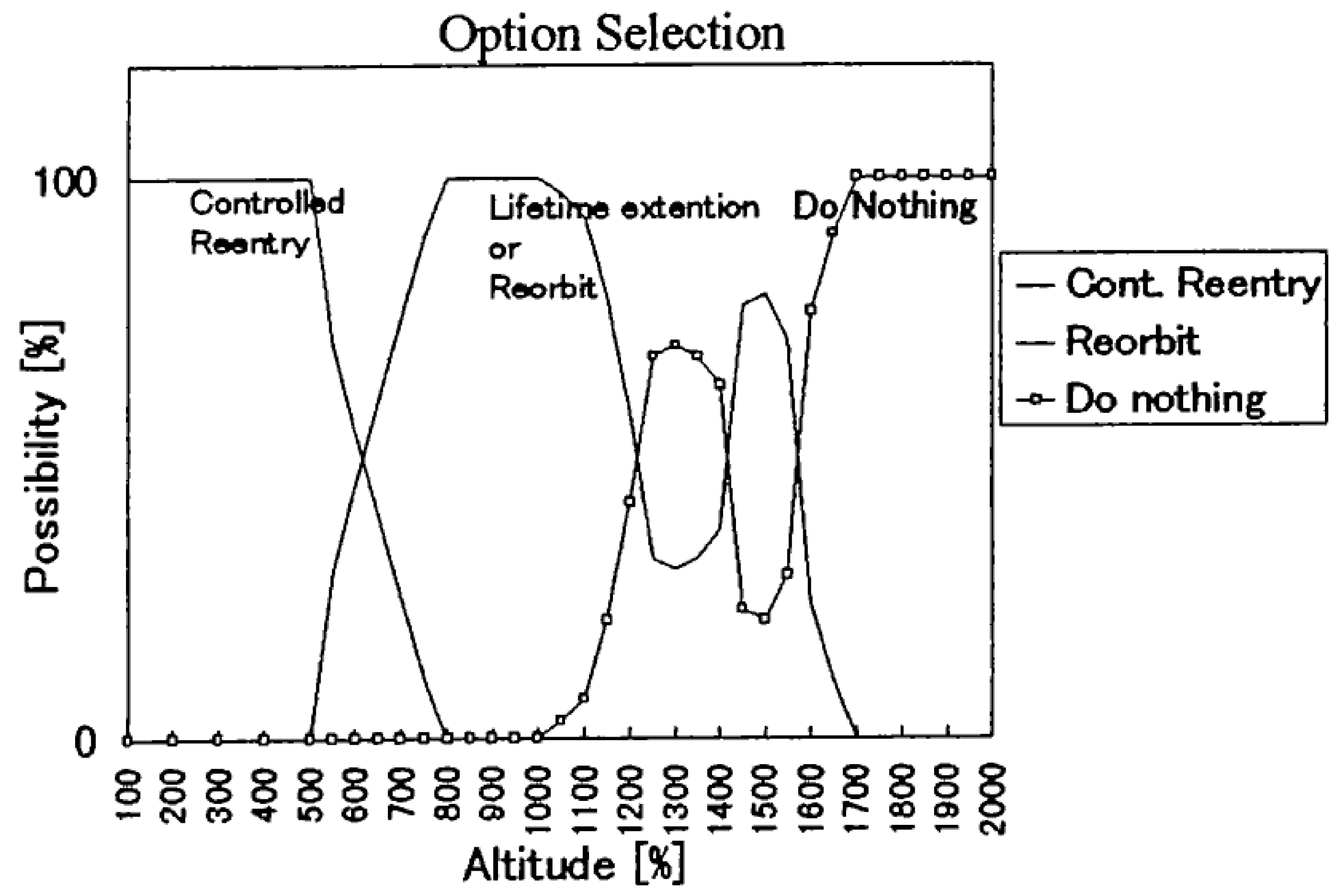
- Uncertainty of reentry survivability
- Weight margin for propellant
- International trend
- Consensus for reorbit
- Future debris environment

3.3.2 If reentry risk is not acceptable

In this case, basic requirement should be controlled reentry. Intentional lifetime reduction can't be taken to keep the ground safety. But to conduct controlled reentry, the orbit should be decreased enough into low altitude. So if the available propellant is limited to 5% of initial mass of space system, applicable altitude may be below 500km.
If it is difficult to conduct controlled reentry because of its height of altitude, reorbit to the graveyard orbit or lifetime extension may be required. However there is a problem that the region, where the controlled reentry is difficult, has big debris density.
Although our principal is to keep the ground safety, we may need international consensus before conducting lifetime extension actually.

The fundamental problem is the uncertainty of reentry survivability and not-established technique for controlled reentry.
Tentative guideline may show the possibility to adapt one of options as follows.

Fig. 2 Concept of Possibility of Option Selection



There will be following factors to be considered in selecting one of options in practical situation.

- Uncertainty of reentry survivability
- Not-established technique for controlled reentry
- Weight margin for propellant
- International trend
- Domestic social circumstance
- Consensus for reorbit

Discussion about reorbit from LEO is written in paragraph 3.4.

3.4 Discussion on merit & demerit of reorbit

Reorbit maneuver has following merits as well as demerits. Final tailoring should be done after reviewing following factors.

(1) Merit
- To throw away into higher orbit results in smaller contribution on debris density because of bigger volume along the orbit ring.
- Existing debris density is small than lower orbit.
- Chance of interference with useful orbit is smaller for hundreds years.
- Infrastructure to retrieve debris may be expected in future.
- If reentry casualty is not acceptable and controlled reentry is impossible, there are no other ways.

(2) Demerit
- Unused objects will be accumulated in graveyard.
- Graveyard may be turned to useful orbit in future.
- Longer lifetime may cause bigger number of collision.
- If breakup occurs, fragments will reach to useful orbit

3.5 Tentative tailoring guide

Draft handbook will show the guideline for systems like the followings:

(1) Until the reentry casualty analysis tool is accepted, the requirements for disposal for LEO spacecraft will not be applied. Otherwise the system should be treated to have unacceptable casualty area, unless its reentry casualty is verified to be acceptable. The acceptable criteria may be the same value as defined in NASA guideline. (Ref. 3)
(2) Until the procedure to conduct controlled reentry is established, the related requirement will be tailored off.
(3) Reorbit maneuver will not be applied until the other agency, which has same guideline (Ref.3), shows the example, and the international understanding admits the justification of reorbit maneuver.

4. FUTURE MITIGATION PLAN

4.1 Major purposes

We should plan debris mitigation activities from the points of view that we should apply better solution for disposal, and promote protection techniques which contribute also as mitigation measures.

4.2 For better solution for disposal in LEO

Most important issues depend on that if we can judge the reentry casualty is acceptable or not.
As far as we analyze reentry casualties for the upper stage and the typical spacecraft, both values can't be acceptable for ground safety. The risk may proven by the recent fact that Delta upper stage tank fallen down in Texas on Jan. 22, 1997. Yet there are another reports that man-made objects from the space caused damage to Japanese and German ships in 1969.
However there is big difference in the result of analysis for reentry casualty between NASA and NASDA. Now we have started joint survey for analysis method under the annual meeting for Safety Management. (NASA proposed to check our tool.)

It isn't clear that which tool is better to present actual phenomena, but we should improve analysis methods for more adequate value.
If the acceptable ground casualties could be determined through international consensus, a certain analysis method should be established as a standard tool throughout the world.

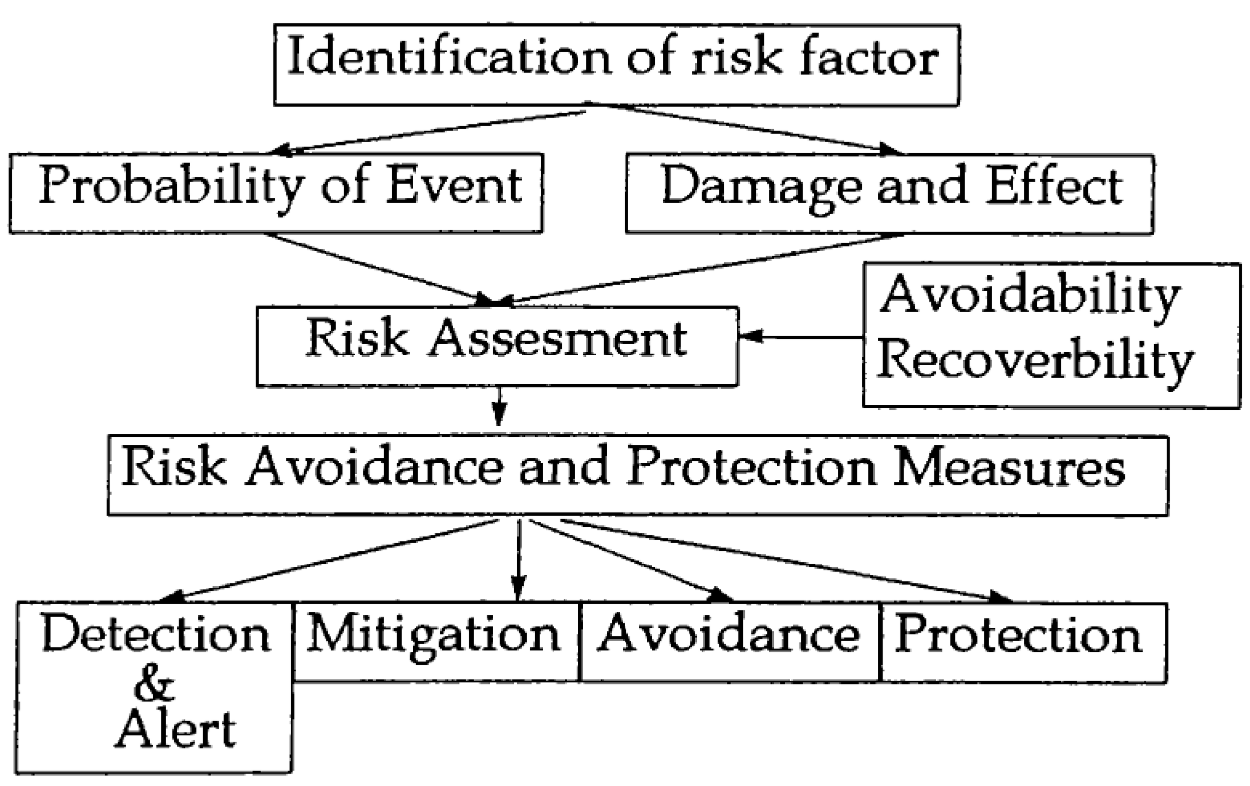
Next issue is the technique for controlled reentry.
If reentry survivability cannot be reduced, the solution may be controlled reentry into international waters. However, there are many technical problems and issues for study for NASDA.

So, we must identify these issues as most important, and our next activities should not exclude these issues.

4.3 Risk control approach

In order to control debris generation as early as possible, we hurried to establish Mitigation Standard. So that the fundamental risk control approach has not been taken enough yet.
Risk control approach should proceed in following path.

Fig.3 Risk Controle Approach



The important step among above steps is risk assessment. Risk assessment should be conducted with the factors of possibility of risk events and damages and its effects caused by the risk events. Feasibility of the risk avoidance and recovery from the damage may be taken into consideration. For the risk of collision are assessed by statistical model and deterministic model. For the risk in reentry, we can know the number of systems impact on the ground, and predict its number for near future. Damage and its effect have not been studied yet in NASDA. So next step in NASDA should includes the promotion of risk assessment.

4.3.1 WBS for NASDA debris activities

Followings is the proposed WBS for debris activities in NASDA. Underlined parts is now under going or applied for budged acquiring for FY1997. I'd like to know the same kind of WBS of other agency to review our plan, and try to coordinate for cooperation.

10000 Identification of risk factor
11000 Survey for risk factor
12000 Observation
- 12100 Facility for Observation
  - 12110 Ground observation facility
  - 12120 On-orbit observation system
- 12200 Data analysis tool
  - 12210 Software for orbit determination
- 12300 Real-time debris monitoring
  - 12310 Real-time detection of breakups
  - 12320 Prediction and alert of collision
  - 12330 On-board sensor for approaching debris
- 12400 Observation of Reentry object

20000 Prediction of probabilities of risk event
- 21000 Modeling
  - 21100 Contribution to IADC Common DB
  - 21200 Study for ESA Model and NASA Model
  - 21300 Development of NASDA model
- 22000 Deterministic model
  - 22100 Operation of Space Object Database
  - 22200 Development NASDA Deterministic Model
- 23000 Statistical model
  - 23100 Operation of Space Environment Database
  - 23200 Development NASDA Statistical Mode
  - 23300 Development debris cloud generation and distribution simulation analysis
- 24000 Reentry analysis
  - 24100 Prediction reentry trajectory

30000 Study for damage and effects caused by debris
- 31000 Estimate damage and its effect of collision
  - 31100 Estimation of energy of collision
  - 31200 Damage thresholds of the space systems
  - 31300 Critical area on space system to cause serious damage

31400 Identify serious effect of damage
32000 Reentry casualty
32100 Analysis method for reentry casualty
32200 Study the criteria of reentry casualty
32300 Survey historical impact events
32400 Assess the casualty for typical systems

40000 Risk assessment
41000 Identification of important risk
42000 Assessment of each risk
43000 Review the scenario of major events
43000 Establishment of acceptable criteria of risk
44000 Planning risk avoidance and protection

50000 Mitigation
51000 Reduce the generation of debris
51100 Preventing on-orbit breakups
51110 Intentional destruction
51120 Residual propellant and other fluids
51130 Batteries
51140 Explosive device
51150 Depletion of separated apogee engine
51200 Reduce the operational debris
51210 Released parts
51220 Lower fairing for multiple launching
51230 Tether device
52000 Preservation of GEO
52100 Adequate reorbit distance
52200 Improvement of the precision for measuring residual propellant
52230 Retraction of the paddle and antenna
53000 Preservation of LEO
53100 Deorbit and reorbit
53110 Improvement of thruster for maneuver
53120 Retraction of the paddle and antenna
53130 Drag enhancement device
53200 Technique for controlled reentry
53210 Study and analysis of reentry trajectory
53220 Prediction of impact point
53230 Breakup analysis during reentry
53230 Destruction for safe reentry
53240 Structure to withstand aerodynamic force
53250 Definition of allowable impact area
53300 Avoidance of risk by uncontrolled reentry
53310 Development of reentry analysis tool
53320 Design to reduce the reentry survivability
53400 Retrieval just after mission termination
53410 Study for on-orbit retrieval by STS
53420 Study of retrieval by reentering capsule
53500 On-orbit retrieval of existing debris
53510 Retrieval by STS
53520 Retrieval by orbit service vehicles (OSV)
53530 Reboost by generating thrust force
54000 Disposal of the upper stage
54100 Lifetime reduction by G-force of sun & moon
54200 Study of controlled reentry
54210 guidance method, reentry trajectory, etc.
54220 Improvement of associated components
54300 Reduction of reentry survivability

60000 Protection and collision avoidance
61000 Protection
61100 Space station (Bumper is being developed)
61200 for traditional spacecraft
61210 Allowable collision risk, shielding effects
61220 Bumper shield for critical components
62000 Avoidance operation
62100 Launch vehicle (COLA.)
62200 HOPE (avoidance maneuver, etc.)
62300 Spacecraft

70000 Detection & Alert
(same as 12000)

80000 Regulation and Documentation
81000 Debris Mitigation Standard
81100 Handbook of STD
82000 S/C Debris Protection Design Criteria
83000 Orbital Operation Manual

5 CONCLUSION

NASDA establish Debris Mitigation Standard and most important issues (on-orbit breakups and reorbit from GEO) will be improved.
But as far as the post-mission disposal from LEO concerned, some orbit regions are very difficult to comply with the requirements perfectly without drastic effort.
NASDA is developing tailoring guide to select adequate option of mitigation measures and is promoting R&D to solve the issues.

6. REFERENCE

1. *Space Debris Mitigation Standard*, NASDA-STD-18, March, 1996.
2. Kato *NASDA Space Debris Mitigation Standard*, IAF-96-V.6.06, October, 1996
3. *Guidelines and Assessment Procedures for Limiting Orbital Debris*, NASA Safety Standard, 1740.14, August, 1995.