B1

世界のデブリ関連規制の動向

Current situation of the international space debris mitigation standards

加藤 明(宇宙航空研究開発機構)
Akira Kato (JAXA)

スペースデブリの発生の防止と衝突被害からの保護のための規格やガイドラインが様々な国際機関、国の政府、宇宙機関などから発行されている。国際標準化機構(ISO)でも種々の規格や技術レポートを発行し、現在も作成作業を続けている。これら規格の全貌を紹介し、他の世界の規格類と比較して紹介する。また、現在日本から提案し、制定作業中の「デブリ対策設計・運用マニュアル」の趣旨を説明する。このアニュアルにて ISO のデブリ対策活動の全貌が把握でき、システムレベルからコンポーネントレベルまでのデブリ対策活動の要点が包括的に理解できることを願っている。

Several debris mitigation standards and guidelines have been developed in the international organizations, the administrations of national governments, and national space agencies. The international organization for standardization (ISO) has also developed and being developed various debris related standards and technical reports. This presentation will introduce them and show the comparison among them. Also the current work to develop the “Space Debris Mitigation Design and Operation Manual” for spacecraft and launch vehicle orbital stages, which were submitted from Japan, will be introduced. This manual will support the space engineers to understand the total concept of the debris mitigation measures in ISO, and present recommendable activities with the hardware oriented manners for design and operation of the spacecraft subsystems and components.

世界のデブリ関連規制の動向
Current situation of the international space debris mitigation standards

JAXA研究開発本部第6回スペースデブリワークショップ
JAXA Space Debris Work Shop

17-19 December 2014, Tokyo, Japan

加藤　明 [JAXA　安全･信頼性推進部、（併）研究開発本部]
Akira Kato, JAXA
Dr. ENG and P.E. Jp（Aerospace System）

1

内容
Contents

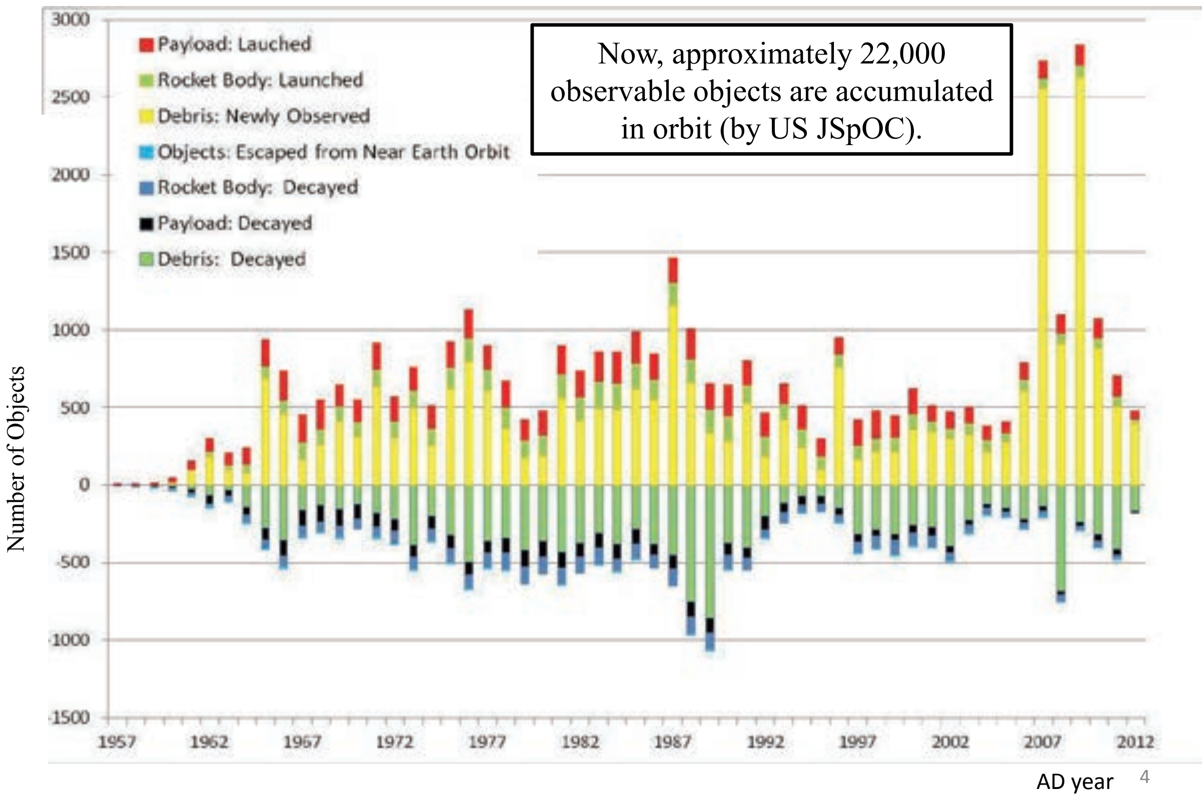
1. 軌道環境とデブリ衝突リスク
   Orbital Environment and Risk of Debris Impact
2. デブリの発生要因
   Major factors of debris generation
3. 世界のデブリ低減規格／ガイドライン
   Global Debris Mitigation Standards and Guidelines
4. 国際標準化機構(ISO)における取組み
   Activities in ISO

2

1.軌道環境とデブリ衝突リスク
Orbital Environment and Risk of Debris Impact

3

Figure 1 Number of Objects Newly Observed or Decayed (or Escaped) Every Year
(Ref. Data from Satellite Situation Report / Space-Track / USSTRATCOM, @June 25, 2012) (processed by A. Kato)



4

Fig.-2 Number of Orbital Objects observed from the ground by US

(size > 10 cm in LEO, size > 1 m in GEO) @2014-9-3

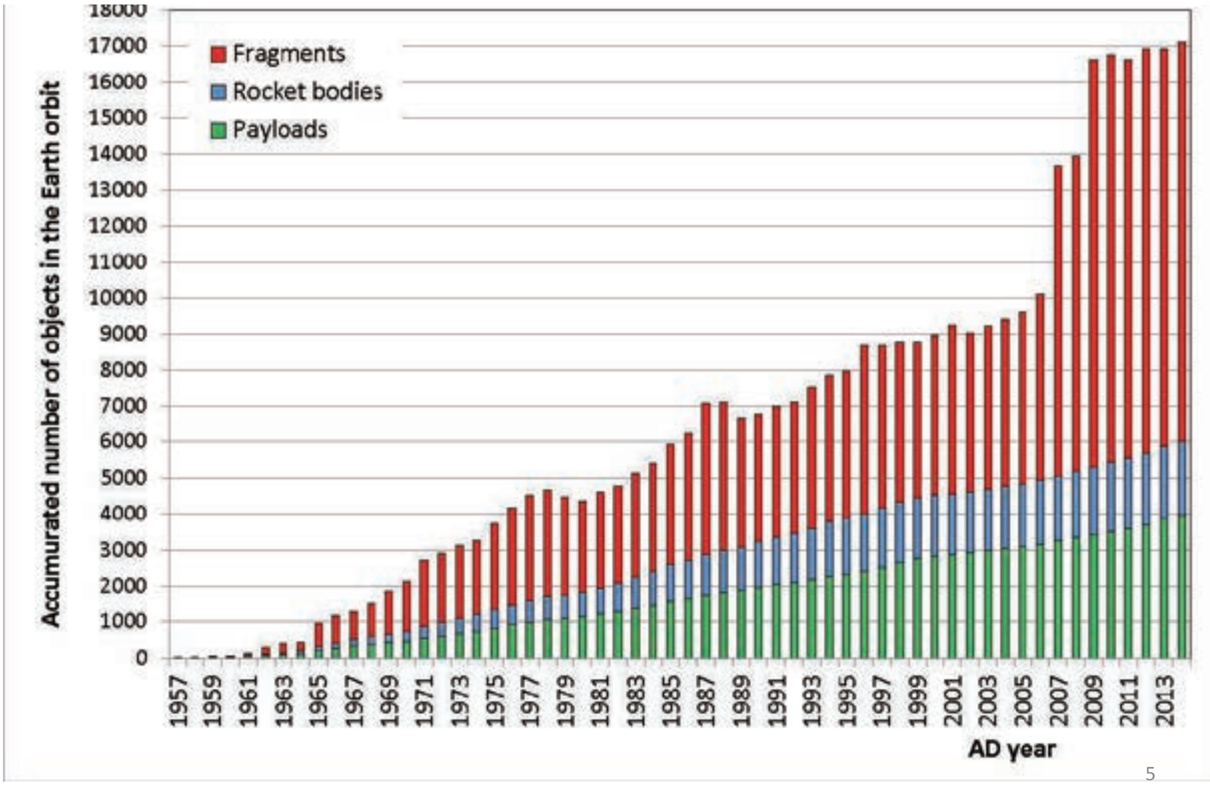
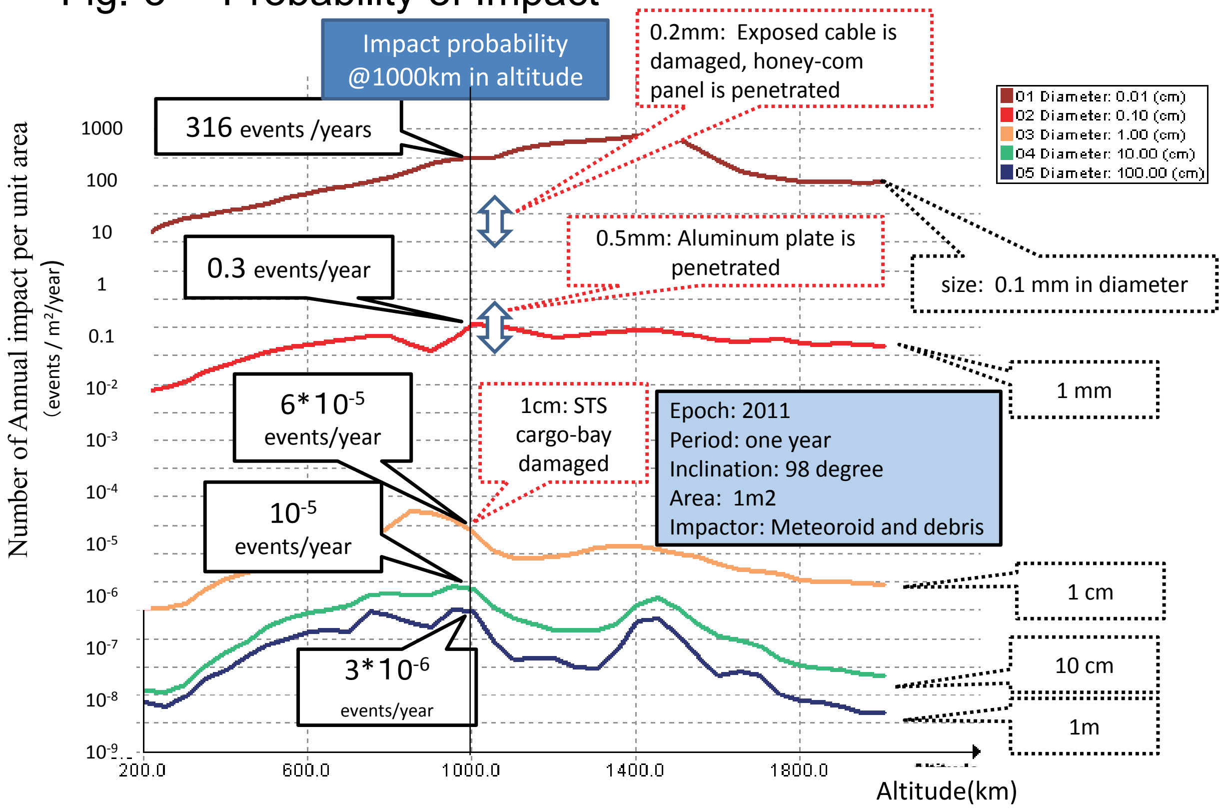


Fig.-3 Probability of Impact



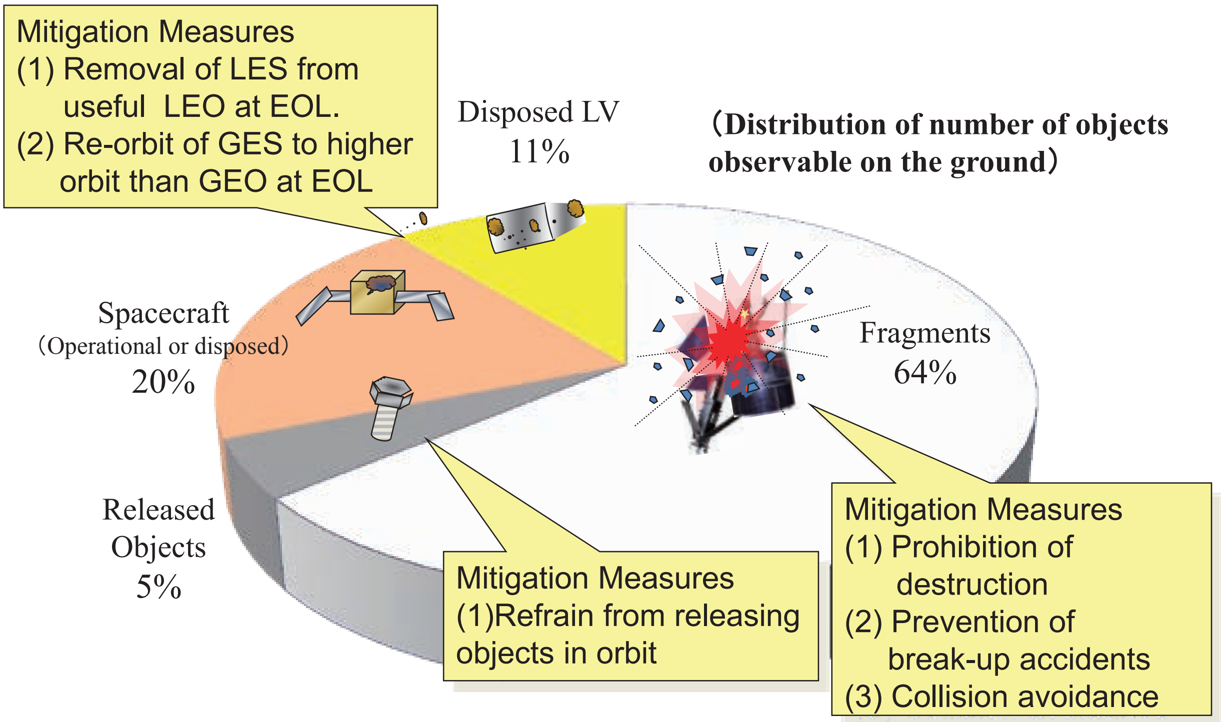
Number of annual Impact according to Altitude (Analyzed by DAS-2/NASA)

6

2. デブリの発生要因
Major factors of debris generation

7

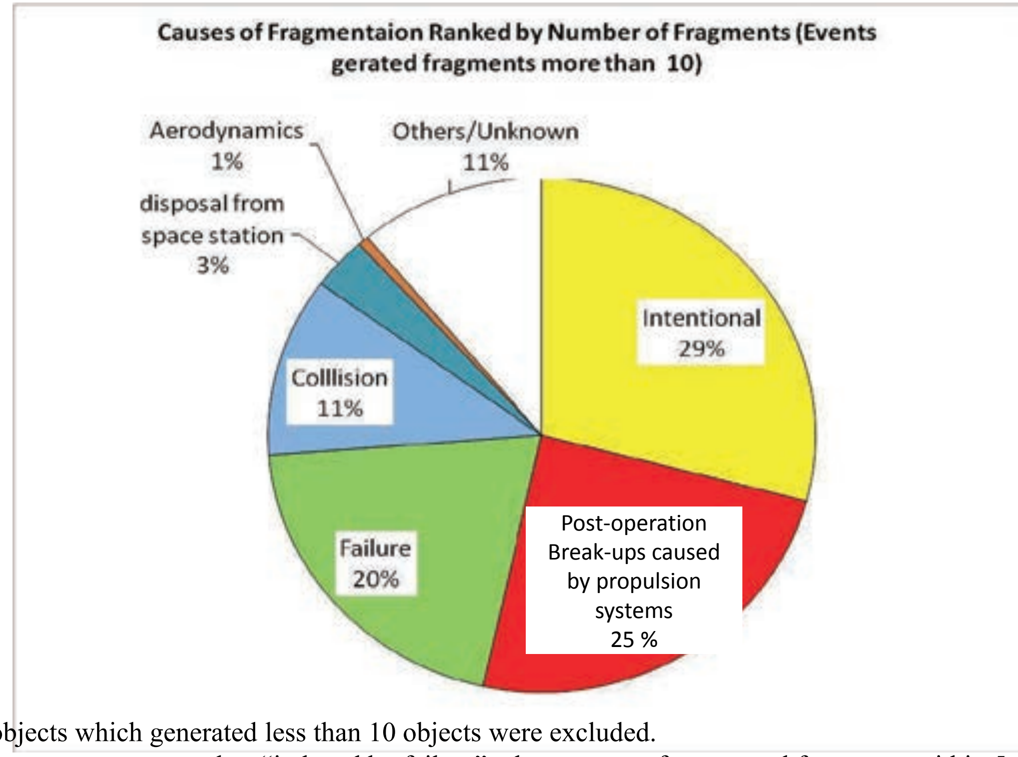
Fig.-5 Causes of Debris Generation and Mitigation Measures



Data from a report of ESA presented at UNCOPUOS/STSC Conference held in February, 2011

8

Fig. 7: Distribution of Causes of Debris According to the Number of Fragments



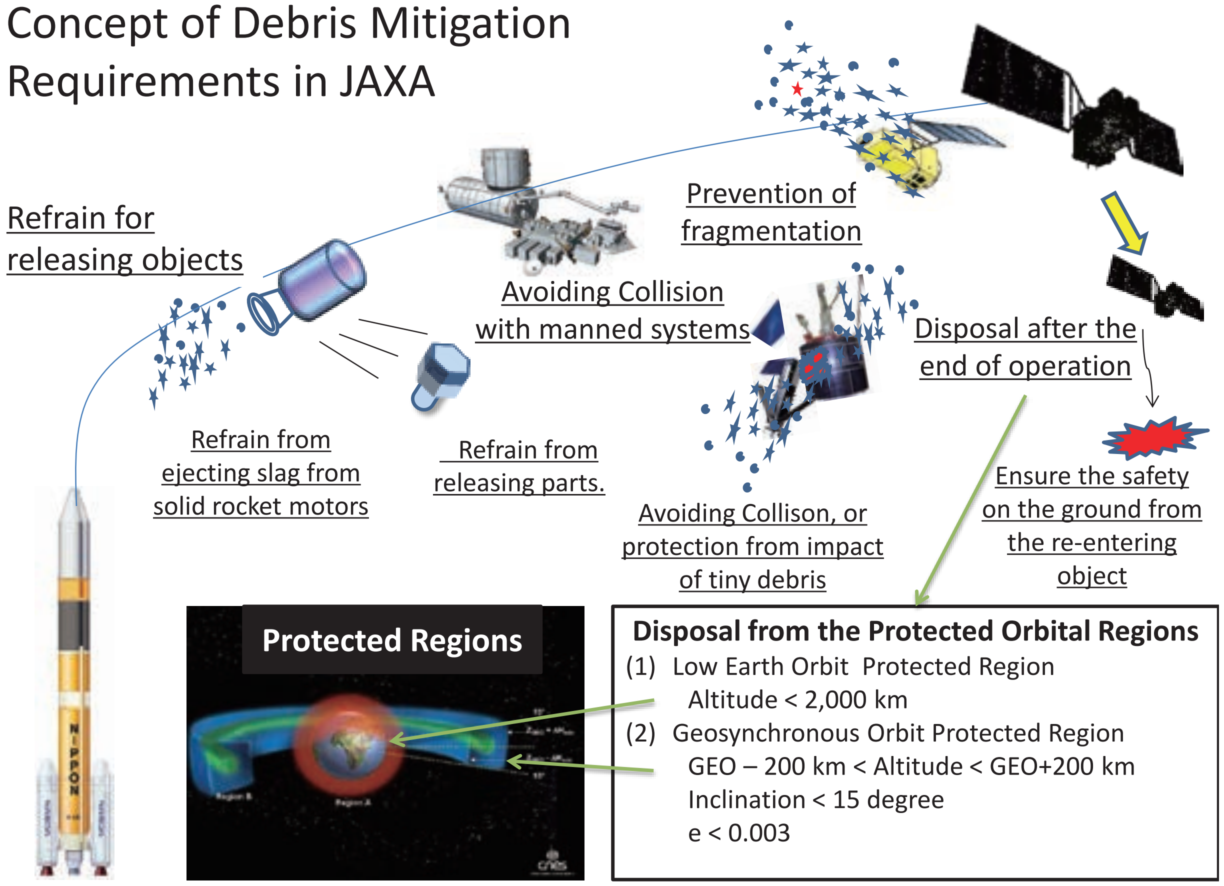
The objects which generated less than 10 objects were excluded.
The events were assumed as “induced by failure” when spacecraft generated fragments within 5 years after launching, or the launch vehicles caused break-ups on the same day of launching.

9

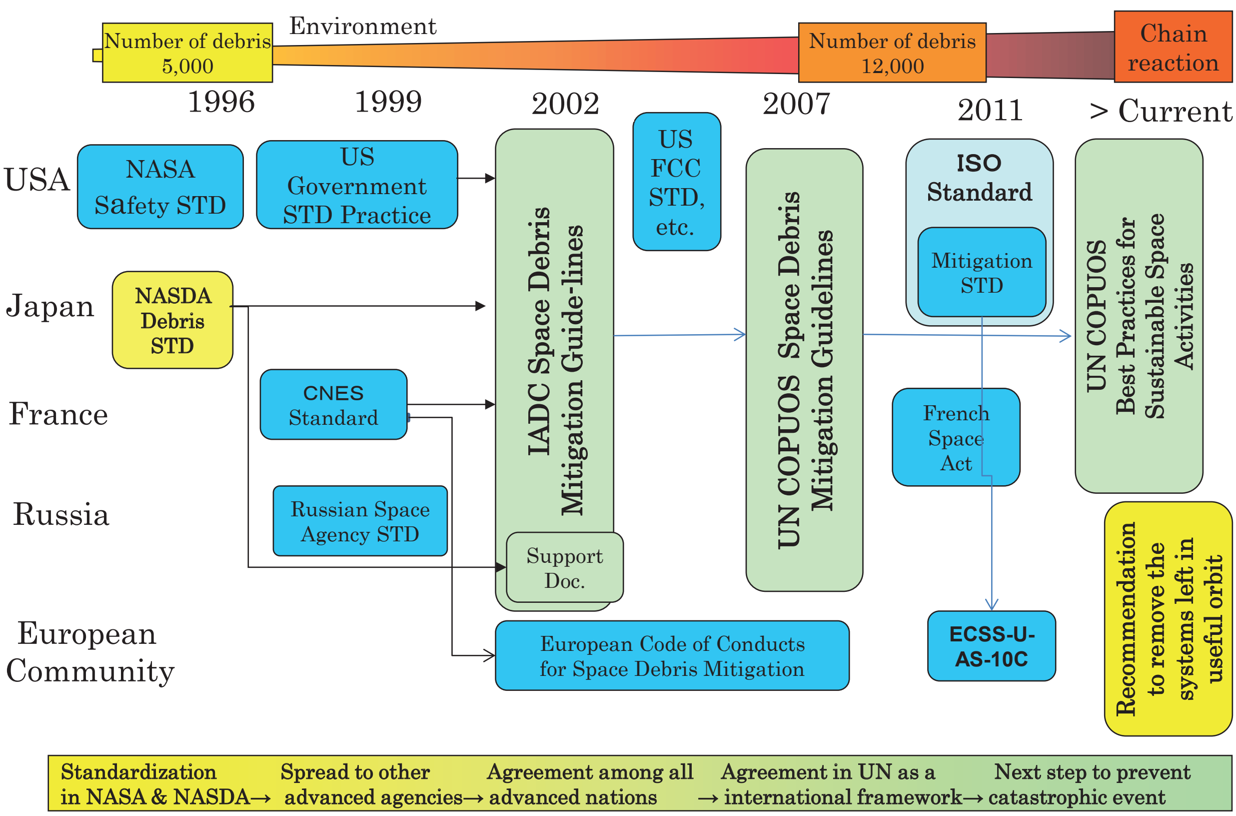
3.世界のデブリ低減規格／ガイドライン Global Debris Mitigation Standards and Guidelines

10

Concept of Debris Mitigation Requirements in JAXA



History of the Regulation for Debris Mitigation



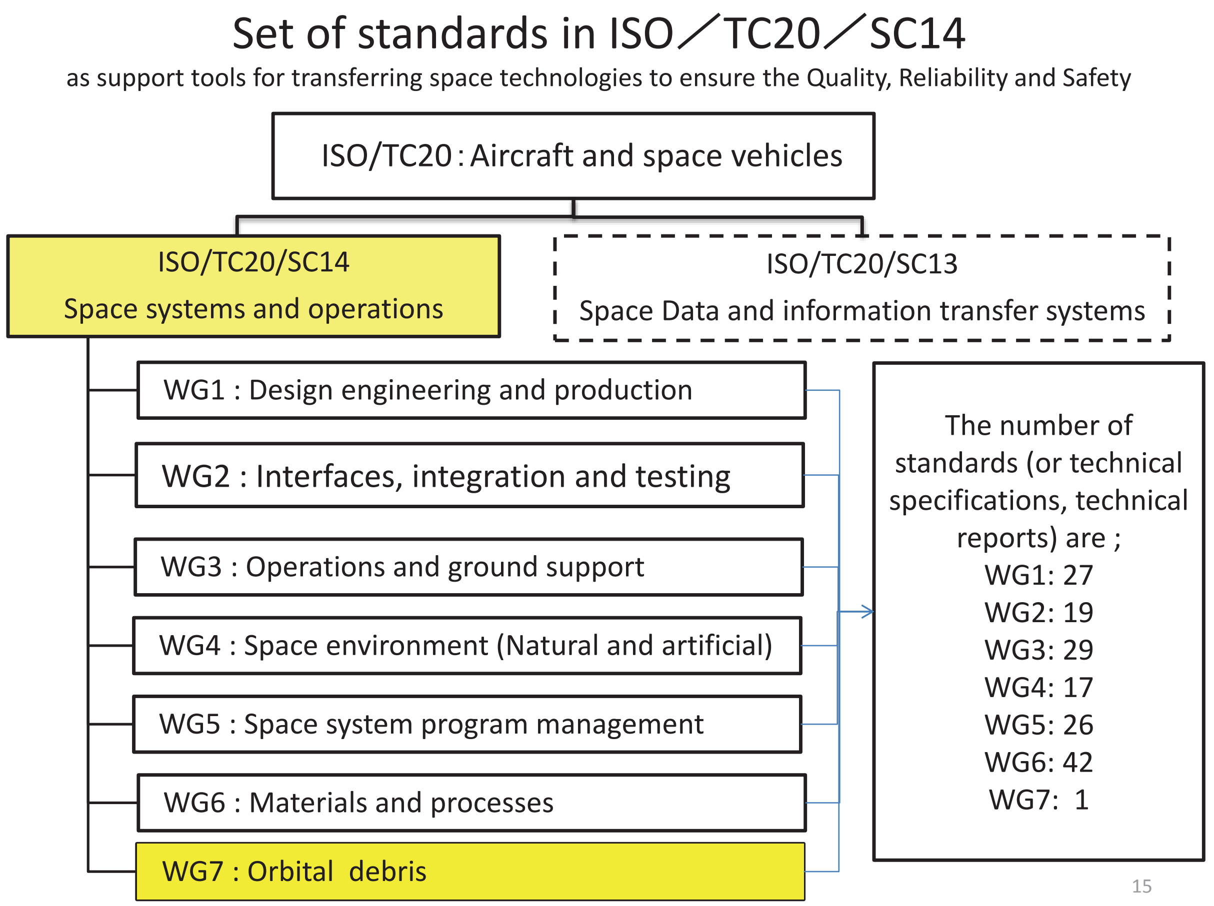
Global debris mitigation rules and JAXA standard

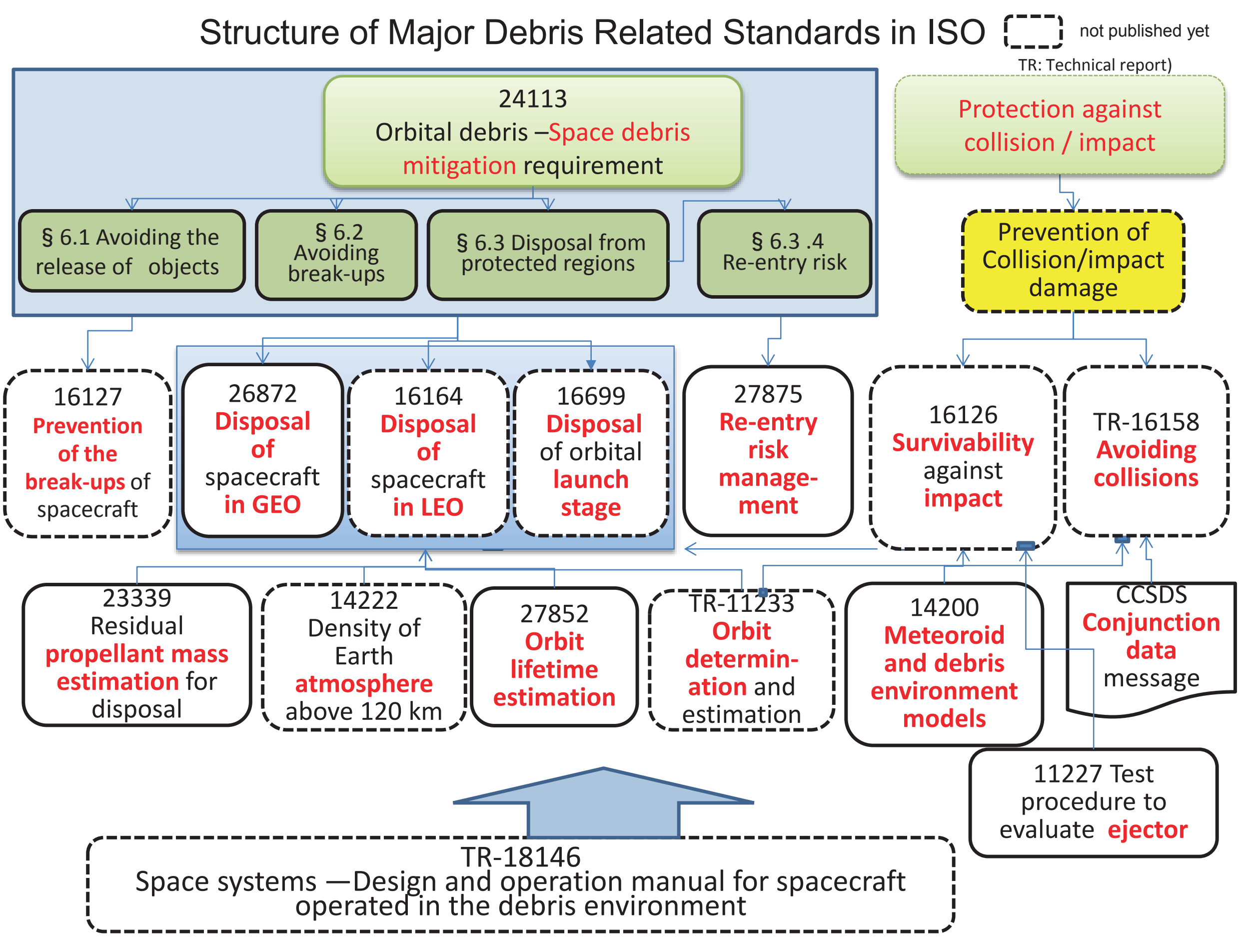
The requirements are almost common including other various standards and guidelines.

		Measures	ISO Standards (or Technical Reports)	JAXA (JMR-003B)	IADC Guidelines[g]
Limiting Debris Generation	*Released Objects*	General idea to refrain from releasing objects	**ISO-24113 / §6.1.1**	Required	§ 5.1
		Slag from Solid Motor	**ISO-24113 / §6.1.2.2, §6.1.2.3**	Required	--
		Combustion Products from Pyrotechnics	**ISO-24113 / §6.1.2.1** (Combustion Products < 1 mm)	Combustion products < 1 mm	--
	On-orbital Breakups	Intentional Destruction	**ISO-24113 / §6.2.1**	Required	§ 5.2.3
		Accident During Operation	**ISO-24113 / §6.2.2** (Probability < 10^{-3})	Required (Monitoring) (Probability < 10^{-3})	§ 5.2.2 (Monitoring)
		Post mission Breakup (Passivation, etc.)	**ISO-24113 / §6.2.2.3 (Detailed in ISO-16127)** (Probability < 10^{-3})	Required	§ 5.2.1
Disposal at End of Operation	***GEO***	Reorbit at EOL	**ISO-24113 / §6.3.2 (Detailed in ISO-26872)** §6.3.2.2: 235 km+ (1,000・Cr・A/m), e < 0.003 §6.3.1: Success Probability > 0.9	235 km+ (1,000・Cr・A/m) e < 0.003 Success Probability >0.9	§ 5.3.1 235 km+ (1,000・Cr・A/m), e < 0.003
	LEO (MEO)	Reduction of Orbital Lifetime	**ISO-24113 / §6.3.3 (Detailed in ISO-16164)** §6.3.3.1: EOL Lifetime < 25years §6.3.1: Success Probability >0.9	EOL Lifetime < 25years Success Probability > 0.9	§ 5.3.2 (Recommend 25 years)
		Transfer to Graveyard	**ISO-24113 / §6.3.3.2 (f)** (guarantee 100 years' non-interference)	Required	Mentioned in recommendation-6
		Other manners	**ISO-24113 / §6.3.3.2 (a) ~ (e)**	--	§ 5.3.2
Re-entry		Ground Casualty	**ISO-24113 / §6.3.4 (Detailed in ISO-27875)**	Controlled with Ec	§ 5.3.2
Collision Avoidance with Large Debris			**ISO-16158**	Required (CAM, COLA)	§5.4
Protection from Impact of Tiny Debris			**ISO-16126**	Required	§ 5.4

13

4.国際標準化機構(ISO)における取組み
Activities in ISO


Set of standards in ISO／TC20／SC14
as support tools for transferring space technologies to ensure the Quality, Reliability and Safety
ISO/TC20 : Aircraft and space vehicles
ISO/TC20/SC14
Space systems and operations
ISO/TC20/SC13
Space Data and information transfer systems
WG1 : Design engineering and production
WG2 : Interfaces, integration and testing
WG3 : Operations and ground support
WG4 : Space environment (Natural and artificial)
WG5 : Space system program management
WG6 : Materials and processes
WG7 : Orbital debris
The number of standards (or technical specifications, technical reports) are ;
WG1: 27
WG2: 19
WG3: 29
WG4: 17
WG5: 26
WG6: 42
WG7: 1
15


Structure of Major Debris Related Standards in ISO
not published yet
TR: Technical report)
24113
Orbital debris –Space debris mitigation requirement
§ 6.1 Avoiding the release of objects
§ 6.2 Avoiding break-ups
§ 6.3 Disposal from protected regions
§ 6.3 .4 Re-entry risk
Protection against collision / impact
Prevention of Collision/impact damage
16127 Prevention of the break-ups of spacecraft
26872 Disposal of spacecraft in GEO
16164 Disposal of spacecraft in LEO
16699 Disposal of orbital launch stage
27875 Re-entry risk manage-ment
16126 Survivability against impact
TR-16158 Avoiding collisions
23339 Residual propellant mass estimation for disposal
14222 Density of Earth atmosphere above 120 km
27852 Orbit lifetime estimation
TR-11233 Orbit determin-ation and estimation
14200 Meteoroid and debris environment models
CCSDS Conjunction data message
11227 Test procedure to evaluate ejector
TR-18146
Space systems —Design and operation manual for spacecraft operated in the debris environment

1. 宇宙機用デブリ低減設計・運用マニュアルの趣旨
Scope of TR-18146

(1) デブリ関連規格の増加への対処

Since there are so many debris related standards, engineers must refer many of them, and pick up the requirements for their responsible work from them.

Need a catalogue of standards and comprehensive linkage among them

(2) フェーズドプランニングへの適時対応

Since the some debris mitigation requirements should be take into consideration from the early phase,

Need a table to encourage the timely practices along the phased plan.

(3) 具体的作業への展開

High level standard (ISO-24113) presents requirements simply, and various medium level standard present what should be done. Need practical guidance but not in strict requirements rather as informative and soft –document as a Technical Report.

(4) サブシステム・機器設計者への推奨作業

Since high level requirements in ISO-24113 and medium level requirements are presented in objective oriented manner, while engineers need to be shown in hardware oriented manner.

Need integration of requirements and help to convert them into design specifications and allocate them to the lower subsystems and components

[Detail requirements are not imposed in this manual, but soften informative recommendable practices are provided to support sub-system engineers.]

17

記述内容 Structure of TR-18146

1. Scope

↓

2. Related Documents (ISO-STD system)

↓

3. Requirements and system-level methodologies for complying with them
Debris Mitigation(MRO, Break-up, Disposal) , Ground Safety from Re-entering Objects, Protection from Debris Impact

↓

4. Consideration in Development Lifecycle
Requirement Analysis & Definition, Conceptual Design, Definition of System, Preliminary & Detail Design, Operation, & Disposal (re-orbit, re-entry, etc.)

↓

5. System Level Considerations
Mission Analysis and Design, Allocation of resources (Mass, Propellant & Power)

↓

6. Subsystem/Component design and operation
(How to design their sub-system to comply with requirements for Refrain from releasing parts, Breakup prevention, Operation for disposal, Ground safety, Re-entry control, Collision avoidance, Protection from Impact of tiny debris.)

↓

Propulsion Sub-System	Orbit & Attitude Control Sub-System	Electric Power Control Sub-System	TT&C Control Sub-System	Structure & Thermal Control Sub-System

18

Requirements and system-level methodologies (Clause-3 in TR-18146)

(1) rationale or justification of requirements in high level standards (24113, etc.) as a support document for them, and

(2) what should be done, and work break-down for that,

Typically, works are broken-down and presented as following table.

Low level STDs will be introduced to see the detail. (Linkage will be cleared.)

Example: Table-1 Work breakdown for preventing orbital break-ups

Process	Subjects	Major works
Preventive measures	Identification of sources of breakup	Identify components that may cause fragmentation during or after operation. **(ISO-16127)**
	Design measures	(1) Prevent accidental break-up during operation. Provide functions to monitor symptoms of break-up. (2) Provide functions for depleting stored energy sources at the end of operation (3) Prohibit intentional break-up. **(ISO-16127)**
	Limiting the probability of B/U	Limit the probability of break-up by reliability design. **(ISO-24113)**
Risk detection	Monitoring during operation	Periodically monitor critical parameters. Take immediate actions if the symptom of a malfunction that could lead to a breakup is detected. **(ISO-16127)**
Counter measures	Preventive measures for break-up	If this kind of condition is detected, terminate the mission operation, and proceed to the disposal process Perform the disposal operations **(ISO-16164, -26872)**

19

Consideration in Development Lifecycle (Clause-4)

Major works related to debris in each phase

Phase / Subjects	Pre-phase A: Mission analysis phase Phase A: Feasibility phase	Phase B: Definition phase Phase C: Development phase Phase D: Production phase	Phase E: Utilization phase	Phase F: Disposal phase
System-level work	1) Input debris related requirements 2) Clarify debris related design philosophy and input them to the system requirements & specification	1) Propellant allocation (including disposal, collision avoidance, controlled re-entry, etc.) 2) Mass allocation (including protection shields, propellants for debris issues, etc.)	1) Transfer debris-mitigation plan to operators. 2) Fix the procedure to determine the operation termination	1) Final determination for disposal action (including disposal maneuver, break-up prevention, controlled re-entry)
Quality Assurance	1) Clarify QA design philosophy 2) Define QA program including parts program	1) Ensure that the probability of successful disposal, non-break-up, and so on, are all high	1) Identify a disposal action for use in case of failure.	2) Ensure that the probability of successful disposal is high
Limiting of debris generation (ISO-24113/6.1)	1) Clarify debris-mitigation design philosophy	1) Fix the design to limit releasing objects, limit their orbital lifetime, etc. 2) Identify the energy sources of fragmentation, and design measures to prevent them.	1) Monitor critical parameters to check symptoms of critical malfunctions that lead to break-ups or prevent disposal actions.	1) Vent residual energy. 2) Terminate operation in the proper sequence.
Disposal (ISO-24113/6.3)	1) Clarify disposal concept 2) Estimate propellant for disposal	1) Design a propulsion subsystem for the planned disposal maneuver.	1) Monitor the residual propellant and identify the end-of-operation time in a timely manner.	1) Remove spacecraft to avoid interference with protected regions.
Re-entry safety (ISO-24113/6.3.4)	1) Clarify re-entry safety concept 2) Define re-entry survivability analysis method 3) Determine whether or not to apply controlled re-entry	1) Design a propulsion subsystem and attitude control system for controlled re-entry, if needed.		1) Conduct controlled re-entry.
Collision avoidance	1) Clarify avoidance procedures 2) Define debris population model and database to monitor the orbital objects	1) Design a propulsion subsystem for collision avoidance. 2) Allocate an amount of propellant for avoidance maneuvers	1) Perform periodic conjunction analysis, and determination of avoidance maneuvers, if needed.	
Impact protection	1) Clarify protection design philosophy 2) Define the debris population model and ballistic limit equations. 3) Estimate mass for shielding.	1) Protection design for vulnerable components to guarantee disposal function at least.		

20

System Level considerations (Clause-5)

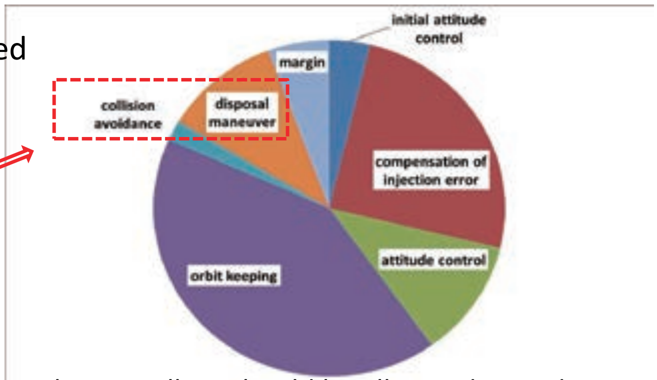
Debris mitigation measures effect on system design.
Clause 5 will present relation among mitigation works and following system design.

(1) Mission design
(2) Mass allocation
(3) Propellant allocation
(4) Power allocation

For example, followings are warned not to forget in allocation of propellant.

a. disposal operations
b. controlled re-entry, if it is planned
c. collision avoidance maneuvers

Debris mitigation design recommends not to forget those factors.



Example: Propellant should be allocated considering debris related consumption

Subsystem/Component design and operation (Clause-6) (1/2)

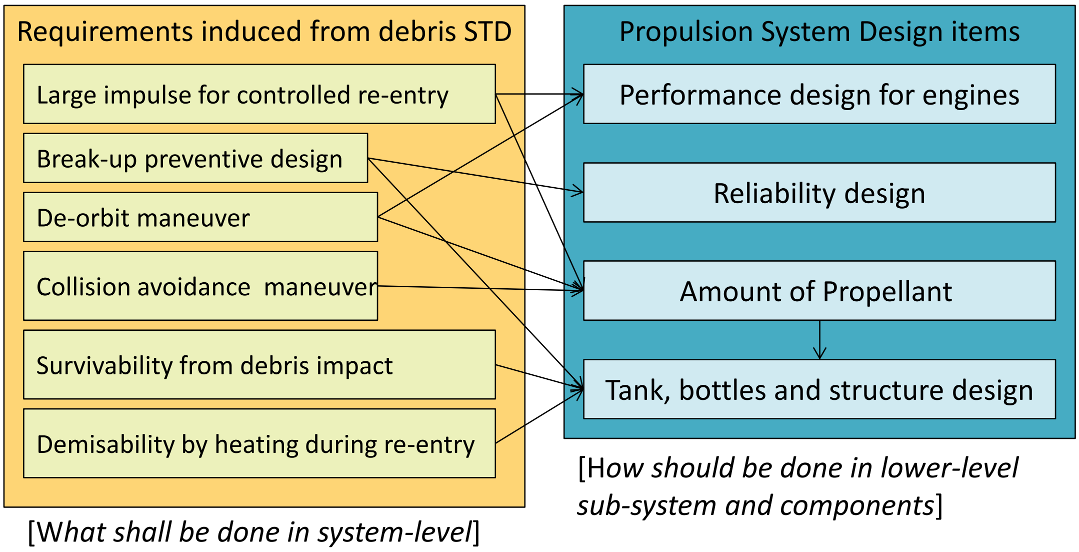
Clause 6 will show how the debris mitigation requirements will be converted to design specifications and allocated to the lower sub-systems and components.
Sub-system engineers will grasp what they should do.

Table debris mitigation requirements and Linkage with functions allocated to sub-system

No	Debris-related items and practices	Necessity of subsystem-level functions					
		Propulsion RCS	AOCS /GNC	Power	TT&C	Structure	Thermal
1	Decrease (control) the number of separation/release items a) Parts released from fasteners, etc. b) slag from solid motors	Yes		Yes	Yes	Yes	
2	Prevent break-up in orbit after the end of operation due to: a) chemical explosion b) rupture of high-pressure vessels c) rotating devices	Yes Yes	Related	Yes			Yes
3	Monitor critical parameters to prevent break-up in orbit during operation	Yes	Related	Yes	Related		Related
4	Remove the spacecraft from protected orbital regions: a) Provide functionality for disposal maneuvers b) Measure residual propellant with high accuracy c) Choose an operation terminating sequence	Yes Yes	Yes	Yes	Related Related Related		
5	Ground safety from re-entering objects a) improvement of survivability b) prevention of pollution on the ground from toxic substance, etc. c) controlled re-entry	Yes Yes Yes	Yes		Yes	Yes Yes	
6	Collision avoidance for large objects a) conjunction assessment, and collision avoidance	Yes	Yes		Related		
7	Protection against the impact of micro-debris a) protection design	Yes	Related	Yes	Related	Yes	Related

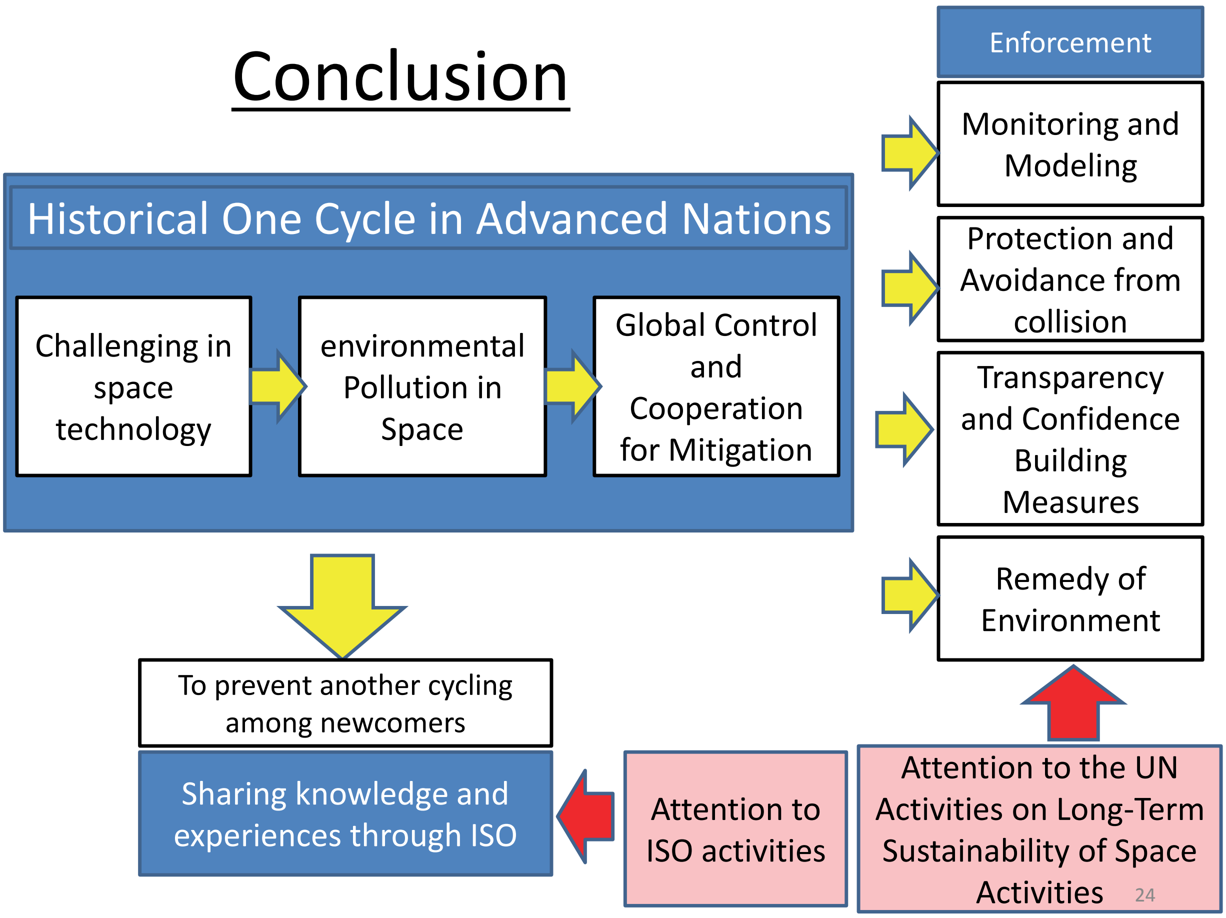
Subsystem/Component design and operation (Clause-6) (2/2)

Following is an example of the propulsion sub-system. Debris related standards present various requirements. Many of them are satisfied by propulsion engineers, but since they are not presented in hardware oriented manner, those engineers must pick-up related requirements from them and integrate them, and convert them into design specifications.



23

Conclusion



24