JMR-003E (E)

General

SPACE DEBRIS MITIGATION STANDARD

April 27 2023

Japan Aerospace Exploration Agency

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Published by
Japan Aerospace Exploration Agency
Safety and Mission Assurance Department
2-1-1 Sengen Tsukuba-shi,Ibaraki 305-8505, Japan

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1 GENERAL

1.1 PURPOSE

The Space Debris Mitigation Standard specifies the mitigation measures which should be taken during the planning, design and operational phases of launch vehicles and spacecraft (hereafter called space systems) in order to minimize the generation of space debris in Earth orbit, lunar orbit, Mars orbit, stable Earth-Moon Lagrange Point, and stable Sun-Earth Lagrange point during launch, orbital injection, on-orbit operation, and after the end of mission. And moreover, it also contributes limiting the occurrence of human casualties due to space debris.

The following four measures are specified essentially in this standard:

(1) Minimizing the number of objects released in Earth orbit during normal operation of a space systems. The same methodology should apply to lunar orbit, Mars orbit, stable Earth-Moon Lagrange point, and stable Sun-Earth Lagrange point.

(2) Preventing the on-orbit break-up of a space system during normal operation and after the end of its mission which could generate a large amount of debris in Earth orbit and lunar orbit.

(3) Reducing interference of a disposed space systems with low Earth orbit (LEO) protected region and geostationary Earth orbit (GEO) protected region. The same methodology should apply to 12-hour-period Earth orbital region, lunar orbit, Mars orbit, stable Earth-Moon Lagrange point, and stable Sun-Earth Lagrange point.

(4) Avoiding human casualties and pollution of the Earth environment made by survived space systems which re-entered to the Earth.

Note: In response to the Artemis Accords, JMR-003E added "lunar orbit", "Mars orbit", "stable Earth-Moon Lagrange point", and "stable Sun-Earth Lagrange" point as the regions where debris generation should be minimized in addition to Earth orbit. The section 5 tentatively defines requirements that are technically feasible at present.

1.2 SCOPE

1.2.1 Applicability

This standard is applied to all space systems and their components developed by JAXA that may interfere with Earth orbit (especially LEO protected region and GEO protected region), lunar orbit, Mars orbit, stable Earth-Moon Lagrange point, and stable Sun-Earth Lagrange point. However, it could be exempted when an alternative requirement is specified in the program, such as the ISS.

Note 1: According to ISO 24113, the debris mitigation management is applicable to Earth orbit where is defined as "bounded and unbounded Keplerian orbits with Earth at a focal point, and Lagrange point orbits which include Earth as one of the two main bodies". However, It notes that "it is not necessary to consider space objects in unbounded Keplerian orbits if their probability of interference with the LEO and GEO protected regions is negligible."

Note 2: For lunar orbit, Mars orbit, stable Earth-Moon Lagrange point, and stable Sun-Earth Lagrange point, objects that remain in place for a long period are in the scope.

This standard is applied to both JAXA project organizations and contractor who develops a space system. This standard intends to specify additional requirements and recommendations from the perspective of space debris mitigation in addition to sufficient measures for mission assurance of an applied space systems.

1.2.2 Tailoring

The requirements in this standard may be tailored before being applied. The results of tailoring, however, shall be coordinated with Safety and Mission Assurance (S&MA) Department and be reviewed by JAXA Safety Review Board, if required. The results of tailoring shall be described in the Space Debris Mitigation Plan (SDMP).

The typical rationales of tailoring are as follows:

(1) For space systems being in development, only feasible requirements would be applied.

(2) Only feasible requirements are applied based on comprehensive examination such as economical and technical feasibility, effect on reliability, benchmarking with world trend, and other conditions related to space debris mitigation measures.

1.3 RELATION WITH OTHER CONTRACTUAL REQUIREMENTS

Any conflicts between the requirements herein and those in contractual documents will be coordinated. The requirements in this standard may be exempted when identical requirements in other standards are already in place. The contractor shall clarify relationships and applicability of multiple requirements in case of duplication, and document it in the Space Debris Mitigation Plan (SDMP) described in 4.2.3.

2. RELATED DOCUMENTS

(1) Applicable Documents

a. JERG-1-007: Safety Regulation for Launch Site Operation
b. JERG-0-047: Safety standard for controlled re-entry
c. JERG-2-144: Micro-debris Impact Survivability Assessment Procedure
d. JERG-0-001: Technical Standard For High Pressure Gas Equipment For Space Use
e. JMR-014: Planetary Protection Requirements
f. JERG-2-026: Safety Standard for ON-ORBIT Servicing Missions
g. Guidelines on License Related to Control of Spacecraft

(2) Reference Documents

a. ISO-24113: Space debris mitigation requirements
b. JMR-003-HB001: Space debris mitigation design and operation manual for spacecraft
c. JMR-003-HB002: Space debris mitigation design and operation manual for launch vehicle
d. Space debris mitigation guidelines of COPUOS, UN Office for Outer Space Affairs, 2010
e. IADC-01-0.2, IADC Space Debris Mitigation Guidelines, (revision 2, March 2020)

3. DEFINITION

3.1 DEFINITION OF TERMS

The definitions of terms used in this standard are given below.

(1) Spacecraft

A system designed to perform a series of tasks or functions in outer space, actively or passively, excluding launch vehicle.

(2) Space system
A generic term for systems performing a mission in outer space, such as a spacecraft or a launch vehicle.

(3) End of mission
When the designated spacecraft operation ends, or when a spacecraft or a launch vehicle upper stage goes into disposal operation.

(4) Retrieval
Capturing a space system in space and transporting it to Earth.

(5) Preservation of the orbital environment
Preservation of the orbital environment as much as possible while actively using it.

(6) Probability of accidental break-up
Probability of all known failure modes capable of causing an accidental break-up, excluding those from external sources such as impacts with space debris and meteoroids.

(7) Collision avoidance capability
Capability to avoid a collision with an orbital object for which an conjunction alert has been issued. It is typically the capability to change orbits.

(8) Space debris
A non-functional object originated by human in Earth orbit, lunar orbit, Mars orbit, stable Earth-Moon Lagrange point, and stable Sun-Earth Lagrange point, including accessories separated from space systems, fragments generated by break-ups, and space systems that have completed their missions.

(9) Slags
Combustion residue generated during the combustion process of solid propellant and discharged to the outside of the motor.

(10) Objects released during normal operation
Fasteners, protectors, lower fairings and other objects which are separated and released onto the orbit according to the design during normal operation of the space system. Paint flakes and other materials released by aging and deterioration are exempted.

(11) Disposal by the reduction of orbital lifetime
Removing a space system from orbit by descending its orbit.

(12) Disposal operation
It is a series of operations such as removal from the protected regions, break-up prevention measures and off-the-air which are performed upon end of a spacecraft operation in order to preserve operational orbit.

(13) Probability of successful disposal
Probability to complete actions for break-up prevention and removal of a spacecraft from protected regions that are required at the end of mission.

(14) Disposal phase
The timeframe performing disposal operation (orbital change maneuvers, venting residual propellants, passivation of batteries, etc.) after the end of mission.

(15) Break-ups
Phenomenon that generates space debris from a space system in orbit due to explosion, rupture with stored energy, or a collision with other object.
Break-ups do not include separation of a part of a space system due to degradation by aging and aerodynamic destruction upon re-entry.

Note: In this standard, the sentence "extreme break-up" is used to express a break-up event such that generates large amount of fragments and does not retain original shapes.

(16) Protected orbital region
A currently useful orbital region where is designated to be maintained. This includes the LEO protected region, 12-hour-period Earth orbital region, and GEO protected region, defined respectively as follows.

a. LEO protected region: 2,000km in altitude and lower
b. 12-hour-period Earth orbital region: Orbital region between 19,100km and 23,500km
c. GEO protected region: GEO +/- 200km within +/- 15 deg inclination

(17) Meteoroid
Naturally-derived objects that exist in the universe. It originates mainly from asteroids or comets.

(18) Effective life
The period while an item can be used effectively (useful life). That is, the period between the beginning of use and the time when an item is no longer functional or reliable due to significant failure rate.

(19) Natural decay
The fall of orbital objects toward the Earth without application of intentional force. It is distinguished from intentional reduction of orbital lifetime by decelerating the object, and controlled re-entry, in which the fall time and fragments dispersion area are controlled.

(20) Ground casualty risk
Scale indicating risk on the ground of the Earth upon impact of surviving re-entered objects from outer space. There are evaluating indexes such as casualty area calculated from the projected area of impacting object with consideration of standing human envelope. And total number of persons to be injured by an event calculated with casualty area, hereafter called “expected number of casualties”. The equations for casualty area and expected number of casualties are defined in the Attachment.

(21) Launch Vehicles
Launch Vehicles for launching a spacecraft. The upper stage left in Earth orbit after launch is called orbital stage.

3.2 DEFINITION OF ABBREVIATIONS

The definition of the abbreviations used in this standard is given below.

(1) GEO: Geostationary Earth Orbit
(2) GTO: Geostationary Transfer Orbit
(3) LEO: Low-Earth Orbit

4. GENERAL REQUIREMENTS

4.1 BASIC REQUIREMENTS

Project organizations and contractors shall plan and conduct effective measures to minimize space debris generation in planning and executing the development and operation of space systems, as coordinated with JAXA.

The associated activities shall include the followings:

(1) Considerations for space debris mitigation measures in studying the development plans of comprehensive systems including space systems and related ground systems.
(2) Efforts to minimize the generation of debris in the design and manufacturing phases of space systems.
(3) Efforts to minimize the generation of debris during the launch and orbital injection of space systems.
(4) Efforts to minimize the generation of debris during the orbital operation phase and the disposal phase on mission completion.
(5) Efforts to minimize the generation of debris, even in the event of failures during the on-orbit operation phase.
(6) Establishment and improvement of the management system to reflect the efforts requested by the above paragraphs (1) through (5) to respective development and operation phases.

4.2 SPACE DEBRIS MITIGATION MANAGEMENT

4.2.1 Outline

Responsible organization for each step in development and operations by JAXA, hereafter called “Project organizations,” and contractors shall properly plan and perform space debris mitigation measures effectively through design and operation phases, then manage these outcomes under predefined organizational control for review.

4.2.2 Organization

4.2.2.1 Organization for the space debris mitigation management

Project organizations and contractors shall establish a responsible organization in order to properly study, plan, and implement each space debris mitigation measure required in this standard. Assigned organization or individuals shall be with authority and resources to accomplish their responsibilities and shall report the status of their progress to the project managers.

4.2.2.2 Organization for the spacecraft operation management

The project organization shall perform an operation management with an appropriate organizational structure and work allocation. Operation management includes proprietary information and communication management, personnel management (personnel training, work management, etc.), spacecraft safety and availability management, and information security management, in addition to various managements necessary for mission execution.

4.2.3 Management Plan

4.2.3.1 Space Debris Mitigation Plan (SDMP)

The Project organization shall develop and document a feasible Space Debris Mitigation Plan (SDMP) as coordinated with S&MA Department. The plan will be subjected to the review by JAXA Safety Review Board, if required.
Contractors shall draft their SDMP that include contents (1) through (4) based on SDMP presented by JAXA, then have approval from JAXA.

(1) The responsibilities and functions of the organizations regarding planning, evaluation, review and implementation of space debris mitigation measures against every cause of space debris generation listed in this standard
(2) The description and rationale for tailoring, if any.
(3) Description of work and schedule of mitigation activity against each cause of space debris generation.
(4) List of documents which will be prepared to satisfy the requirements of this standard, and other related documents including applicable documents.

4.2.3.2 Spacecraft Operation Management Plan (SOMP)

The project organization shall document plans necessary for managing the spacecraft operations. SOMP shall include descriptions and charts about organizations related to the following subjects required by Section 6.3.4 of the "Guidelines on License Related to Control of Spacecraft" (Cabinet Office).

a. Spacecraft operation
b. Emergency response
c. Information security

4.3 MANAGEMENT IN EACH PAHSE OF LIFECYCLE

In the development of space systems, preservation of the orbital environment shall be considered in the system concept as important factor from the beginning of project lifecycle, then it shall be realized in each development phase. For this reason, a formal review shall be conducted in each phase, with submittal of sufficient support data such as analysis conditions. It is also required to define “disposal phase” at the last part of project lifecycle, and adopt measures to minimize negative effect on the orbital environment.

4.3.1 Management in Concept Study, Concept Design and Mission Definition Phases

In developing space systems, it is necessary to study the system concepts, system architecture, mission, launching methods, operation orbit, the way of operation, and the way of disposal so as to capture the purpose in the section 1.1 and space debris mitigation measures required in section 5 shall be taken into consideration. The adequate safety, reliability and quality program shall be planned under the understanding that failure of the space system would cause not only the loss of mission of itself but also deteriorate the orbital environment. The mission objectives shall be considered so as not to adversely affect the orbital environment and other operational space systems upon defining the mission requirements.

4.3.2 Management in Design Phases

Space systems shall be designed to minimize space debris generation during normal operation, and to minimize possibility of themselves to become a space debris. It is required to confirm compliance to design requirements associated with space debris mitigation by the critical design review.

4.3.3 Management in Operation Phases

Checkout operation, normal operation and extended operation (refer to the next section for disposal phase) shall be conducted with consideration for space debris mitigation. The following practices shall be taken.

(1) The spacecraft developer shall inform operator organizations with the relevant criteria and design parameters on the spacecraft such as propellant-measurement-accuracy, propellant-loading-capacity, re-orbiting procedures as a part of data in the operation documents upon spacecraft handover.

(2) The appropriate flight path and relevant events shall be taken into account for the launch vehicle flight trajectory so as to accomplish the disposal of orbital stage (including venting of the residual propellants, orbital change maneuvers, etc.).

(3) Residual propellants shall be confirmed during operation and the decision for mission termination shall be made while necessary amount of the propellants to achieve the re-orbit operation can be guaranteed.

The amount of residual propellants shall be evaluated using the estimation procedure transferred as part of design information with careful observation of the spacecraft conditions.

4.3.4 Management in Disposal Phases

Upon disposal it is required to perform space debris mitigation measures such as removal of spacecraft from the protected regions, removal of residual energy and so on.

5. PLANNING AND IMPLEMENTATION OF THE SPACE DEBRIS MITIGATION MEASURES

5.1 MINIMIZING THE OBJECTS RELEASED DURING NORMAL OPERATIONS

5.1.1 Limitation of Released Components, Parts and Its Fragments

(1) As a general rule, the total number of launch vehicle-related objects (launch vehicle orbital stages and other payload support structures, etc.) left in Earth orbit shall be one or less in case of a single payload launch and two or less in case of multiple payload launch.

(2) Spacecraft shall be designed not to release parts such as fasteners, kick engine that could possibly stay in Earth orbit, unless either serious technical or economical problem would result. For lunar orbit, Mars orbit, stable Earth-Moon Lagrange point, and stable Sun-Earth Lagrange point, it is recommended to adopt the same design constraints as long as mission requirements and cost allow.

(3) For the mission which intentionally separates / releases objects (tether mission, separation of a child spacecraft from its parent spacecraft, etc.), the risk of collision (e.g., a degree of interference) with other spacecraft including inhabitable space systems shall be evaluated based on characteristics of the released object such as the area/mass ratio, orbital lifetime, direction, and velocity. There should be means and conditions to avoid serious situation induced upon separation / release. Separated and released objects shall be disposed of in a manner consistent with Section 5.3. For tethers, it is recommended to adopt robust structure like multi-strand tethers that cannot be easily broken by debris/meteoroids impact, and recommended to retract them after use to reduce the risk of collision.

Note: This requirement is also applicable to the case that equipment is partially separated /released from the spacecraft.

5.1.2 Limitation of combustion products from pyrotechnics and solid rocket motors

(1) Pyrotechnic devices, except for solid rocket motors, shall be designed and used so as not to release combustion products and fragments larger than 1 mm in their largest dimension into Earth orbit.

(2) Solid rocket motors shall be designed and operated so as not to release slag sized 1 mm or larger into GEO protected region and LEO protected region.

Note 1: The main aim of this requirement is to limit the generation of slag debris ejected into GEO protected region and LEO protected region during the final phase of combustion. Slag debris is potentially hazardous to space operations due to its size, number and orbital lifetime. This is particularly the case when slag debris is ejected into a high orbital region where it can pose an impact risk for a long period of time.

Note 2: In the case SRM slag larger than 1mm could be ejected to LEO protected region even with the current best practices, a detailed evaluation shall be made to determine if the risk like cumulative collision probability against other space objects is acceptable.

Note 3: In case there are potential interference with GEO protected region by the object in a transfer orbit toward lunar, planetary, and other long elliptical orbit missions, the compliance will be evaluated on a case-by-case basis.

5.2 PREVENTION OF ON-ORBIT BREAK-UPS

The following on-orbit break-ups shall be prevented.

(1) Break-ups caused by stored energy left in retired space systems
(2) Break-ups caused by stored energy during operation
(3) Extreme break-ups caused by a collision with on-orbit objects during operation
(4) Intentional destruction

5.2.1 Prevention of break-ups caused by stored energy left in retired space systems

In order to prevent break-ups of retired space systems and subsequent generation of space debris in Earth orbit and lunar orbit, space systems shall be designed toward eliminating accidental break-ups to the reasonable extent, and the causes of accidental break-ups shall be removed as much as possible, immediately after the final disposal maneuver or before the retrieval. If the planned re-entry cannot be carried out, the residual energy shall be vent at an appropriate time.
The following measures shall be followed.

(1) Measures for residual liquid propellants and high pressure fluids

Liquid propellants and high pressure fluids left in the retiring space systems shall be used or vent while re-orbiting maneuvers so as not to be a potential cause of break-ups. Otherwise the analysis shall verify that residual fluids will not cause break-ups.
The following measures shall be incorporated in design.

(a) For the bi-propellant propulsion system, especially with the hypergolic propellants, tanks and lines should be designed to prevent unintentional mixing propellants and combustion even after a failure on a piece of parts. The use of hypergolic propellants and oxidizers in the common bulkhead tanks should be avoided because there are many explosions supposed to be induced by mixing two propellants through fatigue bulkhead. In case the common bulkhead tank has to be used, it is necessary to strengthen isolation between two propellants and prove no buckling with expected back pressure per "Technical Standard For High Pressure Gas Equipment For Space Use(JERG-0-001)," and employ vent sequence preventing reversed pressure during disposal operation.
(b) Residual propellants in the tanks and lines should be vent after the end of re-orbiting maneuvers. If simultaneous venting for bi-propellant propulsion system is not feasible, the propellant with higher self-reactivity should be preferentially vented.
(c) If the venting is not feasible, there should be enough safety margins for break-ups even with possible heating, otherwise pressure limiting functions should be incorporated in design.
(d) Vent lines should be designed so that freezing does not prevent venting.

(2) Measures to prevent break-up of batteries

Batteries shall be adequately designed and manufactured, both electrically and mechanically not to cause neither excessive pressure increasing nor structural fracture.
At the end of operations battery charging lines shall be de-activated. If feasible, a battery should have pressure limiting functions to prevent rupture and subsequent damage on a space system.

(3) Flight termination system

Pyrotechnic devices shall have enough margins for spontaneous ignition temperature which considers temperature increasing by solar heating and so on. The command receivers shall be deactivated to eliminate accidental fire, immediately after the flight termination function completed its duty.

(4) Heat pipes, etc.

Sealed pressure systems shall be designed with a sufficient safety margin against rupture with possible heating condition during orbital lifetime.

(5) Rotating equipment

Rotating equipment such as wheels shall be stopped after the end of operations.

5.2.2 Prevention of break-ups during operation of space systems

5.2.2.1 Certainty of design

It should be confirmed in the space system design review that adequate reliability and quality control have been conducted to prevent failures that may lead to break-up events during operation <u>in Earth orbit and lunar orbit</u>. In general, the probability of accidental break-up of a space system shall be 0.001 or less.

5.2.2.2 Monitoring of a spacecraft during operation

For the operation control of spacecraft, the procedures shall document monitoring of malfunctions on propulsion system, batteries, attitude control system, and other function which could lead to the massive generation of space debris when it failed, and proper organizations shall be maintained during operation so that immediate reaction can be taken upon malfunctions. At least the following status shall be monitored from the ground.

(1) Tank pressure and associated temperature to evaluate remaining propellants.
(2) Parameters (temperature and voltage and so on) to detect battery failures.
(3) Parameters to detect attitude control system failure.

5.2.2.3 Space Debris Mitigation Measures in Case of Malfunction

When the malfunctions on the operating spacecraft could lead to a break-up, or a loss of mission essential function, feasible space debris mitigation measures such as removal of residual energy sources, reduction of orbital lifetime, or re-orbiting from protected orbital regions) shall be assessed and executed unless a spacecraft may recover. However, re-orbiting operation shall not be conducted if it should create a subsequent break-up.

5.2.3 Prevention of break-ups caused by a collision with on-orbit objects

5.2.3.1 Selection of operation orbit

GEO spacecraft operations shall always be planned to maintain sufficient relative distance to avoid collisions and resultant break-ups. Operations orbit of spacecrafts on other circular Earth orbit shall always be planned to mitigate the risk of conjunction and collision with other spacecraft operating at the same altitude. In case that rendezvous, docking or related joint missions are planned, "Safety Standard for On-Orbit Servicing Missions (JERG-2-026)" will be applied.

5.2.3.2 Collision avoidance against trackable space objects

Spacecraft with collision avoidance capability shall perform collision avoidance operation if the risk of collision is not acceptable based on the conjunction assessments through mission operation until disposal as long as possible. For proper collision avoidance, it is highly recommended to cooperate with an entity which is capable to provide sufficient conjunction monitoring.

Note: The launch time needs to be coordinated per the dedicated standards so that launch vehicle, spacecraft and other separated objects will not collide to the inhabitable space systems in orbit.

5.2.3.3 Collision avoidance capability

A spacecraft operated in GEO protected region shall be capable to avoid collisions. In general, a spacecraft should be capable to avoid collisions as much as possible.

5.2.3.4 Enhance trackability from the ground

Improving orbital determination by enhancing trackability from the ground makes conjunction analysis and collision avoidance more efficient. Therefore, it is recommended to add optical or radio wave reflectors/transmitters on the spacecraft which could be less trackability during or after the mission.

5.2.3.5 Probability of extreme break-up by space debris or meteoroid impact

(1) In order to determine mission orbit, spacecraft size, weight, number and so on in early development phase (e.g. conceptual design phase), probability of extreme break-up shall be evaluated taking into account for space debris or meteoroid impact to the spacecraft main body and major components (e.g. a service module, a payload module, SAP, Large antennas, etc.).

Note 1: It is not necessary for a spacecraft with a collision avoidance capability to assess the collision probability with the trackable debris which may cause an extreme break-up upon impact.
Note 2: The spacecrafts weighted no more than 100kg, or operating in GEO are not mandated to calculate collision probability with other space objects. However, it is still needed to evaluate collision probability for missions with severe consequence by break-up, such as satellite constellations.

(2) Location and protection design of high-pressure vessels and propellant tanks shall take into account for probability of extreme break-up by space debris or meteoroid impact.

5.2.4 Prohibition of Intentional Destruction

Intentional destruction of a space system in orbit shall not be conducted.

5.3 REMOVAL OF SPACE SYSTEMS FROM PROTECTED ORBITAL REGIONS AFTER THE END OF MISSION

5.3.1 Basic Requirements

The retired space system shall avoid interference with the LEO/GEO protected regions and minimize the risk of break-up according to Section 5.2.1. The probability of successful disposal is 0.9 or higher as a target value. It is assumed that this value could be demonstrated by complying with the requirements in Sections 5.3.1.1 through 5.3.4.

5.3.1.1 Requirements in design phase

5.3.1.1.1 Preparation of decision making procedures for mission termination / extension

Decision making procedures shall be prepared for mission termination / extension of a spacecraft in order to achieve successful post mission disposal.

5.3.1.1.2 Preparation of disposal work plan

Disposal work plan shall be documented to specify the implementation plan for satisfying requirements in this standard, such as re-orbit procedure and passivations upon mission termination.

Note 1: Disposal work plan should include the information on sequences for re-orbiting out of protected regions, passivation and other tasks until off-the-air or the last command for controlled re-entry.
Note 2: Information on disposal sequence for launch vehicles is documented in the flight plan.

5.3.1.1.3 Disposal functions in design

A spacecraft shall be designed to have functions to perform disposal operation.

Note: Disposal functions are to perform passivation defined in section 5.2.1, in addition to re-orbit from protected regions defined in section 5.3.2 and 5.3.3.

5.3.1.1.4 Resources for disposal maneuvers

Resources for disposal maneuvers shall be secured as follows:

(1) Propellants for re-orbit

The sufficient amount of propellants shall be taken into account for design of the spacecraft so as to perform planned re-orbit. Sufficient amount of margin shall be considered to include prediction error of solar activity derived from different launch date and other conditions, performance error of propulsion system and measurement errors.

Note: Prediction of the orbital lifetime for a high elliptical orbit contains a large error due to influence of solar radiation pressure and attractive forces of the sun and the moon. If it is not feasible to reserve propellant for disposal to fulfill the worst error assumption, a target probability to achieve re-orbit satisfying 25 years or less orbital lifetime will be defined, then propellant shall be allocated to satisfy that value. This target probability is independent from the probability of successful disposal.

(2) Electric energy for re-orbit in case of electric propulsion system

When using an electric propulsion system, electric energy shall be managed to support re-orbit.

(3) Design of the measurement and monitoring systems for on-board propellant

A spacecraft shall equip with propellant measurement and monitoring systems which allow to measure the amount of on-board propellants in real-time to support prompt determination for timeline toward the end of the mission. Especially for GEO spacecraft, this measurement and monitoring systems shall support appropriate precision analysis to ensure the re-orbiting delta-V.

5.3.1.1.5 Reliability of disposal functions

The reliability of the disposal function at the end of the disposal operation after the planned operation period shall be evaluated by the method defined in relation to the reliability evaluation based on JMR-004 “Reliability Program Standard.”

Note 1: The planned operation period is generally equivalent to certified design life.

Note 2: Reliability at the end of operation period is also acceptable if the duration of disposal operation is short enough and negligible for calculation.

Note 3: Evaluation for the launch vehicle disposal is the part of mission reliability evaluation based on JMR-004 "Reliability Program Standard".

5.3.1.1.6 Remaining life management for items used for disposal operation

(1) Management of operating life

Operating life shall be determined for life limited items used for disposal operation, and there shall be sufficient margins for the mission duration defined in specifications. If the operation period may be extended, the margin shall also consider additional operation time and cycles for the extended period. In addition, items that require logging operating time and cycles for evaluation of residual life and mission extension/termination shall be identified, then procedures to manage operating life shall be prepared.

(2) Management of aging deterioration

The life limitation shall be determined for items that will deteriorate by aging and could affect the successful disposal of a spacecraft. If the operation period may be extended, the life margin shall properly take into consideration the extended period.

5.3.1.1.7 Plan of health status check for equipments and anomaly response

Health status subjected to periodical check shall be identified for equipments used for spacecraft disposal. The procedure for checking health status for those equipments shall define monitoring parameters and means to measure. Normal range shall be specified for each monitoring parameter and the procedure shall define response action in case a parameter goes out of normal range.

5.3.1.1.8 Effect of space debris impact and protection design

Probability of the loss of disposal functions shall be calculated against impacts by space debris and meteoroid. Critical components and cables shall be in the calculation then protection measures, redundancy and layout change should be considered if the risk is unacceptable. The acceptable criteria shall be defined for each mission taking into account for the technical maturity of collision risk calculation and protection methods. Refer to "Micro-debris Impact Survivability Assessment Procedure (JERG-2-144)" about the collision risk calculation and protection design.

5.3.1.2 Measures during spacecraft operations

5.3.1.2.1 Management of the remaining life of life limited items used for disposal operation

Remaining life of each life limited item shall be logged and reevaluated per Section 5.3.1.1.6.

5.3.1.2.2 Management of resources for disposal maneuvers

The amount of residual propellant and pressurant shall be periodically monitored and mission operation shall be terminated prior to their depletion. When an electric propulsion system is also used for disposal, the electrical energy shall be managed in addition to propellant. The necessary amount of resources shall be updated in timely manner, taking into consideration for operating history such as change in solar activities and equipment deterioration.

5.3.1.2.3 Health status check for equipments and anomaly response

Health status of equipments defined in section 5.3.1.1.7 shall be monitored and evaluated, then those equipments shall be appropriately managed including proper response for anomaly.

5.3.1.2.4 Decision making for mission termination/extension

Spacecraft operation shall be properly terminated considering the importance to complete disposal operation. When extending operation beyond planned period, the following items shall be confirmed, in addition to all items in Sections 5.3.1.2.1 to 5.3.1.2.3 as suggested in the decision making procedure.

(1) The corrective action for failures shall still be valid for further operation.
(2) Propellant and electrical energy shall be reserved for updated disposal plan based on changed disposal schedule.
(3) Mission extension shall be allowed within life limit.
(4) There shall be no concern on a single failure point. In particular, when a single failure point is the result of a failure of redundant system, possible common cause shall be assessed with the estimated root cause and the detail status of the active string.
(5) If there is a configuration change during operation that affects the reliability of the disposal function, the reliability of the disposal function at the end of the disposal operation or at the time of the next operation extension decision shall be evaluated starting from the time of the operation extension decision.

In addition, the added operation period and the time interval for reevaluation shall be set. The same evaluation is iterated for further extension.

5.3.1.3 Confirmation and execution of disposal plan

Disposal work plan shall be carried out with the following remarks in consideration.

Disposal work plan shall be carried out with the following remarks in consideration.

(1) The targeted orbit is determined based on the latest solar activity.
(2) The disposal orbit is determined with consideration of the trajectory fluctuation due to venting of residual fluid after the disposal maneuver.
(3) Communication and commandings are available while disposal operations. The proper arrangement will be in place with other space agencies in case additional stations are needed.

5.3.2 Disposal in GEO region

(1) Space systems that terminate their missions near GEO shall be re-orbited to the orbit where fulfill at least one of the following conditions in order to avoid collision with other spacecrafts in GEO

a) The initial eccentricity after re-orbit is less than 0.003. the minimum perigee altitude delta-H (km) above GEO is calculated by the following equation.

$$\text{delta-H} = 235 + 1000 \times C_R \times A / m \text{ [km]}$$

Where:
C_R: Solar radiation coefficient
A: Effective sectional area of the spacecraft (m^2)
(25% of total surface area)
m: Mass of the spacecraft (kg)

b) The perigee altitude after disposal is sufficiently higher than GEO, and no interference with GEO protected region within 100 years, even accounting long-term perturbation.

(2) Space systems passing through near-GEO, such as GTO missions, shall be planned its apogee altitude to be away from 200km lower than GEO for at least 100 years.

(3) A spacecraft in Inclined geosynchronous orbit (IGSO) is disposed per Section 5.3.2(1) in general, but it can also be disposed to the orbit inducing re-entry to Earth by proper arrangement of orbit inclination, eccentricity, and Right Ascension of Ascending Node. In this case, the cumulative interference period in GEO protected region and LEO protected region shall be within acceptable limits.

5.3.3 Disposal related to LEO region

For the space systems passing through LEO, orbital lifetime after the end of mission shall be minimized as far as possible. The orbital lifetime and the expected number of casualties in the case of natural decay shall be evaluated, and one or more of the following measures (1) through (5) shall be taken while considering the ground safety requirements in Section 5.4. The orbital lifetime shall be calculated considering the perturbation effect caused by attractive force of the moon and the sun, periodic change of the solar activity, and the solar radiation pressure.

Note: Estimation of orbital lifetime for the high elliptical orbit takes into account for the effects shown in the note in Section 5.3.1.1.4 (1).
Note: Selection of measure (1) through (5) depends on technical and/or economic feasibility.

In case of measure (3) through (5), the time count begins at one of the following a through c for ensuring 25 years or less.

a. at the end of mission epoch, for space systems with collision avoidance capability.
b. at the orbit injection epoch, for space systems that do not have collision avoidance capability.
c. at the epoch when it is predicted that they will start interfering with the protected area, for space systems that terminate operation above the LEO protected region and then descend and interfere with the protected region.

(1) Retrieval
Capture space systems in space and transport them to Earth. No object shall be released during retrieval operation.

(2) Controlled re-entry
Re-entry with controlled fashion so as to guarantee the ground safety.

(3) Natural decay
In case the orbital lifetime could naturally be within 25 years by atmospheric drag, the space systems may be left in their operational orbit. Note that the ground risk upon re-entry shall be mitigated in accordance with requirements in 5.4.

(4) Reduction of orbital lifetime
Spacecrafts shall be disposed to an altitude with orbital lifetime no more than 25 years. Note that the ground risk upon re-entry shall be mitigated in accordance with requirements in 5.4.

(5) Reduction of orbital lifetime by deployment devices and tethers
A deployment device shall shorten orbital lifetime of a retired spacecraft to be within 25 years or less. There shall be an assessment on pros and cons for adopting deployment devices, then the contribution to risk reduction such as a lesser cumulative collision probability in orbit shall be clearly estimated.

5.3.4 Disposal in 12-hour-period Earth orbital region
Space systems operated in 12-hour-period Earth orbital region shall be disposed out of the operating region.

5.3.5 Disposal in lunar orbit and Mars orbit
Space systems operating in lunar orbit, Mars orbit shall be disposed in accordance with JMR-014 "Planetary Protection Requirements".

5.3.6 Disposal in stable Earth-Moon Lagrange point and stable Sun-Earth lagrange point

It is recommended that space systems operating at stable Earth-Moon Lagrange point and stable Sun-Earth Lagrange point be disposed not to interfere with these areas.

5.4 REQUIREMENTS FOR DISPOSAL WITH EARTH RE-ENTRY/DESCENT

5.4.1 Safety of the ground

The following requirements shall be met for safety of the ground when space systems are disposed by natural re-entry fashion in LEO. (Spacecraft, etc. returning to the Earth from planets, etc. shall also comply with JMR-014 "Planetary Protection Requirements".)

(1) Risk, i.e. Expected number of casualties (Ec), induced by the ground impact in Earth with surviving objects shall be estimated prior to the launch of the spacecraft. The Ec of spacecraft or launch vehicle shall be less than 1 x 10^{-4}.

Note 1: When a space system does not satisfy this requirement, feasible practices have to be adopted for acceptable Ec.
Note 2: Adoption of design-for demise approach will lead to reduction the Ec.
Note 3: As for like active debris removal, total Ec with multiple objects upon re-entry shall meet the above criteria if they are combined to a single system. This is not the case when multiple objects are not combined upon re-entry.
Note 4: For a spacecraft which is disintegrated to multiple parts upon reentry, total Ec with all related parts shall meet the above criteria.

(2) If the Ec of spacecraft or launch vehicle exceeds 1 x 10^{-4}, controlled re-entry shall be conducted in accordance with JERG-0-047, "Safety Standard for Controlled Re-entry".

5.4.2 Prediction of re-entry and disclosure of related information

JAXA assesses available trajectory information of own space systems using available analysis technique, then predicts re-entry trajectory, day and time. This information is disclosed in appropriate ways.

5.4.3 Prevention of contamination on the ground environmental by on-board materials

If a space system will be re-entered to the earth upon disposal, radioactive substances, toxic substances or any other environmental pollutants shall not be left in surviving fragments, or those effects shall be permissible.

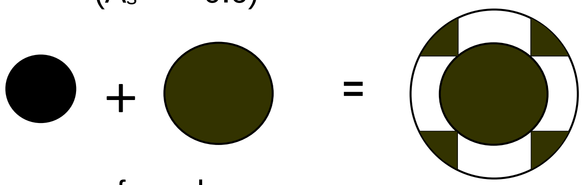
Attachment

1. Casualty area

Casualty area (Ac) is defined based on the projected area of an impacting object and a human surface projection pseudo circle (0.36 m2). This is the area around the projected area of the impacting object plus the area of the radius (33.8 cm) of the human surface projection pseudo circle.
The formulas when the impacting object is a sphere and a polygon are shown below.

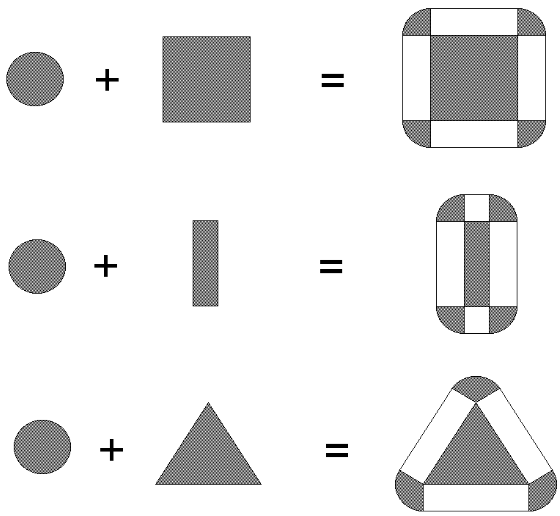
(1) In case of a sphere
From the projected area (As) of Impacting object with radius r_h and the area of the human surface projection pseudo circle.

$$
\begin{aligned}
Ac &= \pi(r + r_h)^2 \\
&= \pi\{(A_s/\pi)^{0.5} + (0.36/\pi)^{0.5}\}^2 \\
&= (A_s^{0.5} + 0.6)^2
\end{aligned}
$$



(2) In case of a polygon

Ac = (projected area of Impacting object) + (perimeter of impacting object x r_h)
+ (the area of the human surface projection pseudo circle)



2. Expected Number of Casualties

Following is an equation for the expected number of casualties (Ec)
Summation should be done within the range of inclination.

$$\mathbf{Ec = Ac \sum_{i=inclination} (Pi\ Ni / Ai)}$$

Where,

Ec = Expected number of casualties [number of people]
Ac = Casualty area [m^2]
Pi = probability of impact in the i-th latitude band [-]
Ni = Number of population in the i-th latitude band [number of people]
Ai = Area of the i-th latitude band [m^2]

Appendix-1: Supplementary information regarding individual projects

(1) Exception for the space science projects

While awaiting the new technology to eliminate harmful slag debris ejected from a solid rocket motor, the requirement regarding limitation of slag debris into LEO protected region defined in section 5.1.2 is exempted for the space science projects. This exception is valid through the end of the space science projects which are initiated during the 4th mid-long term objectives period. The applicability of this exemption in the next mid-long term objectives period will be decided separately.