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Washington, DC 20546**

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Process for Limiting Orbital Debris

**Measurement System Identification:
Metric**

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This document is subject to reviews per Office of Management and Budget Circular A-119, Federal Participation in the Development and Use of Voluntary Standards (02/10/1998) and NPD 7120.10, Technical Standards for NASA Programs and Projects.

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FOREWORD

This NASA-STD is published by the National Aeronautics and Space Administration (NASA) to provide uniform engineering and technical requirements for processes, procedures, practices, and methods that have been endorsed as standard for NASA programs and projects, including requirements for selection, application, and design criteria of an item. This NASA-STD is approved for use by NASA Headquarters and NASA Centers, including Component Facilities. This NASA-STD may be applied on contracts for spacecraft, instrument, or launch vehicle contractors per contractual documentation. Use of this NASA-STD is the responsibility of the user.

Collision with orbital debris is a risk of growing concern as historically-accepted practices and procedures have allowed artificial objects to accumulate in Earth orbit. To limit future debris generation, NASA Procedural Requirements (NPR) 8715.6, “NASA Procedural Requirements for Limiting Orbital Debris,” requires each program and project to conduct a formal assessment of the potential to generate orbital debris during deployment, mission operations, and after the mission has been terminated. This NASA-STD serves as a companion to NPR 8715.6 and provides each NASA program and project with specific requirements and assessment methods to assure compliance with the NPR. This document is required to be used for orbital debris assessments for all payloads, launch vehicle orbital stages, and released objects as required by NPR 8715.6. NASA-Handbook (NASA-HDBK) 8719.14 serves as a reference document to assist orbital debris practitioners and program/project management in understanding the technical, physical, and political aspects of orbital debris.

Note: This NASA-STD superseded NASA Safety Standard (NSS) 1740.14, Guidelines and Assessment Procedures for Limiting Orbital Debris. NPR 8715.6 paragraph P.2.3 permits limited use of this document for long-standing NASA programs.

This NASA-STD is consistent with the objectives of the U.S. National Space Policy of the United States of America (June 2010), the U.S. Government Orbital Debris Mitigation Standard Practices (February 2001), the Inter-Agency Space Debris Coordination Committee (IADC) Space Debris Mitigation Guidelines (October 2002), the Space and Missile Center Orbital Debris Handbook, Technical Report on Space Debris (July 2002), the space debris mitigation guidelines of the Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space, (A/AC.105/720, 1999 and A/AC.105/890, Feb 2007). The requirements contained within this NASA-STD (and NPR 8715.6) encompass the requirements within the U.S. Government Mitigation Standard Practices, the IADC Space Debris Mitigation Guidelines, and the United Nations documents cited above and therefore imply compliance with the requirements in those documents.

Requests for information, corrections, or additions to this NASA-STD may be submitted to the NASA Headquarters Office of Safety and Mission Assurance. This NASA-STD was developed by the NASA Headquarters Office of Safety and Mission Assurance with the Orbital Debris Program Office at Johnson Space Center.



Terrence W. Wilcutt
Chief, Safety and Mission Assurance

December 08, 2011

Approval Date

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Process for Limiting Orbital Debris

1. SCOPE

1.1 Purpose

1.1.1 This document serves as a companion to NASA Procedural Requirements (NPR) 8715.6 and provides specific requirements and methods to comply with the NASA requirements for limiting orbital debris generation. NASA-Standard (NASA-STD) 8719.14 updates and replaces NASA Safety Standard (NSS) 1740.14, which went into effect in August 1995. This NASA-STD helps ensure that spacecraft and launch vehicles meet acceptable standards for limiting orbital debris generation.

Note: Limited use of NSS 1740.14 for programs in effect as of approval of this NASA-STD is per the requirements in NPR 8715.6 paragraph P.2.

1.1.2 This NASA-STD is primarily designed to limit the creation of new orbital debris and, therefore, to limit the risk to other current and future space missions. The methodologies described herein can be used by programs and projects to evaluate and to improve their own mission reliability and success with respect to the orbital debris and meteoroid environment. The assessments described in this NASA-STD are required per NPR 8715.6 and are reviewed for completeness as a part of the flight approval processes.

1.1.3 This document, along with the associated current version of Debris Assessment Software (DAS) or the higher fidelity Object Reentry Survival Analysis Tool (ORSAT), provided by the NASA Orbital Debris Program Office (NASA ODPO) located at Johnson Space Center (JSC), shall be used by the program or project manager as the primary reference in conducting orbital debris assessments ([Requirement 56244](#)).

1.1.4 This NASA-STD establishes requirements for (1) limiting the generation of orbital debris, (2) assessing the risk of collision with existing space debris, (3) assessing the potential of space structures to impact the surface of the Earth, and (4) assessing and limiting the risk associated with the end of mission (EOM) of a space object. In addition to requirements in Section 4 and methods for assessment, this NASA-STD provides the format for the required debris assessment and reports which must be submitted to the Office of Safety and Mission Assurance as required in NPR 8715.6.

Note: NASA-HDBK 8719.14 serves as a reference document to assist orbital debris practitioners and program/project management in understanding orbital debris. Topics in NASA-HDBK 8719.14 include the orbital debris environment, measurements, modeling, shielding, mitigation, and reentry. It is strongly encouraged that the NASA-HDBK be used with the implementation of NPR 8715.6 and NASA-STD 8719.14.

1.1.5 This document is primarily intended for use in assessing orbital debris that is in Earth orbit. For spacecraft and launch vehicles traveling beyond Earth orbit, the beginning of Sections

4.3-4.8 state how the requirements in this NASA-STD are applicable to missions traveling beyond Earth orbit.

1.2 Applicability

- a. This NASA-STD is applicable to all objects launched into space in which NASA has lead involvement and control or has partial involvement with control over design or operations via U.S. internal or international partnership agreements, including the launch vehicle. This document has no automatic exclusions for any program or project due to limited funding, responsibility, or involvement of NASA in the program or project. NASA involvement includes design, manufacture, or funding of instruments, spacecraft bus, spacecraft systems, the launch vehicle, and launch processing. The use of this NASA-STD is only required for those portions of a space mission under NASA control. This NASA-STD defines being in ‘space’ as exceeding 100 km (~62 mi) in altitude and achieving or exceeding Earth orbital velocity.
- b. This NASA-STD has been designed to be cited in contract, program, and other Agency documents as a technical requirement or as a reference for guidance.
- c. Any decision to waive or vary from the requirements in this NASA-STD requires the concurrence of the Chief, Safety and Mission Assurance, Office of Safety and Mission Assurance (Chief/OSMA).
- d. Within this NASA-STD, the word “shall” indicates a mandatory requirement, the word “should” indicates that a statement is strongly recommended for implementation but not required, and the word “may” indicates an optional implementation.
- e. NPR 7120.5 and NPR 8715.6 require the use of this document for development of orbital debris assessments (ODA), ODA Reports (ODAR), and EOM Plans (EOMP).

2. APPLICABLE AND REFERENCE DOCUMENTS

2.1 Applicable Documents

2.1.1 General

The documents listed in this section contain provisions that constitute requirements of this NASA-STD as cited in the text of Section 4. The latest issuance of cited documents is to be used unless otherwise approved by the assigned Technical Authority. The applicable documents are accessible via the NASA Online Directives Information System at <http://nodis3.gsfc.nasa.gov/>, or directly from the Standards Developing Organizations (SDOs) or other document distributors.

2.1.2 Government Documents

NPD 1000.5, Policy for NASA Acquisition.

NPD 8010.3, Notification of Intent to Decommission or Terminate Operating Space Systems and Terminate Missions.

NPR 7120.5, NASA Space Flight Program and Project Management Requirements.

NPR 8715.3, NASA General Safety Program Requirements.

NPR 8715.6, NASA Procedural Requirements for Limiting Orbital Debris.

NASA-STD 8709.22, Safety and Mission Assurance Acronyms, Abbreviations, and Definitions.

2.1.3 Non-Government Documents

Inter-Agency Space Debris Coordination Committee (IADC-02-01) Space Debris Mitigation Guidelines, September 2007 (http://www.iadc-online.org/index.cgi?item=docs_pub).

2.2 Reference Documents

The documents listed in this section contain supporting information to assist in the implementation of the provisions that constitute requirements of this NASA-STD as cited in the text of Section 4. The documents are accessible via the NASA Online Directives Information System at <http://nodis3.gsfc.nasa.gov/>, or directly from the SDO.

United Nations Document V.09-88517, UN Space Debris Mitigation Guidelines of the Committee on the Peaceful Use of Outer Space, January 2010. Available at http://www.orbitaldebris.jsc.nasa.gov/library/Space%20Debris%20Mitigation%20Guidelines_COPUOS.pdf

National Space Policy of the United States of America (June 2010); available at http://www.whitehouse.gov/sites/default/files/national_space_policy_6-28-10.pdf

U.S. Government Orbital Debris Mitigation Standard Practices, February 2001. Available at http://orbitaldebris.jsc.nasa.gov/library/USG_OD_Standard_Practices.pdf

NPD 8020.7, Biological Contamination Control for Outbound and Inbound Planetary Spacecraft (<http://nodis3.gsfc.nasa.gov/>).

NPR 8020.12, Planetary Protection Provisions for Robotic Extraterrestrial Missions (<http://nodis3.gsfc.nasa.gov/>).

NASA Handbook 8719.14, Handbook for Limiting Orbital Debris

U.S. Air Force Space and Missile Center (SMC) Orbital Debris Handbook, (July, 2002) (<http://stinet.dtic.mil/cgi-bin/GetTRDoc?AD=ADA435172&Location=U2&doc=GetTRDoc.pdf>).

JSC-27862, Postmission Disposal of Upper Stages (December 1998) (available through the NASA ODPO).

Debris Assessment Software (DAS) (<http://orbitaldebris.jsc.nasa.gov/mitigate/das.html>).

3. ACRONYMS AND DEFINITIONS

3.1 Acronyms

CDR	Critical Design Review
DAS	Debris Assessment Software
EOM	End of Mission
EOMP	End of Mission Plan
ESA	European Space Agency
GEO	Geosynchronous Earth Orbit
GTO	Geosynchronous Transfer Orbit
HQ	Headquarters
IADC	Inter-Agency Space Debris Coordination Committee
ISO	International Organization for Standardization
LEO	Low Earth Orbit
MEO	Medium Earth Orbit
ODA	Orbital Debris Assessment
ODAR	Orbital Debris Assessment Report
ODPO	NASA Orbital Debris Program Office
OSMA	Office of Safety and Mission Assurance
OSTP	Office of Science and Technology Policy
PDR	Preliminary Design Review
sfu	Solar Flux Unit
SMA	Safety and Mission Assurance
SSN	Space Surveillance Network
SSO	Sun Synchronous Orbit
UN	United Nations

3.2 Definitions

3.2.1 Definitions for SMA terms are found in NASA-STD 8709.22, Safety and Mission Assurance Acronyms, Abbreviations, and Definitions. See NASA-STD 8709.22 for definitions of the following terms which are applicable to this NASA-STD:

- Apogee
- Apsis (pl. apsides)

- Argument of perigee
- Ascending node
- Cratering flux
- Debris flux
- Debris flux to limiting size.
- Disposal
- Geosynchronous Earth Orbit (GEO)
- Geosynchronous Transfer Orbit (GTO)
- Inclination
- Launch vehicle
- Line of apsides
- Line of nodes
- Low Earth Orbit (LEO)
- Meteoroids
- Mission operations
- Orbital debris
- Orbital lifetime
- Orbital Stage
- Passivation
- Penetration debris flux
- Perigee
- Postmission Disposal
- Right ascension of ascending node
- Semi-major axis
- Sun-synchronous Orbit (SSO)
- Space debris
- Space Structures
- Spacecraft
- Stabilized
- Vernal equinox

3.2.2 Terms unique to this NASA-Standard are listed below.

ΔV : The change in the velocity vector caused by thrust measured in units of meters per second.

Eccentricity: The apogee altitude minus perigee altitude of an orbit divided by twice the semi major axis. Eccentricity is zero for circular orbits and less than one for all elliptical orbits.

f_{10} : An index of solar activity; often a 13-month running average of the energy flux from the Sun measured at a wavelength of 10.7 cm, expressed in units of 10^4 janskys.

Jansky: A unit of electromagnetic power density equal to 10^{-26} watts/m²/Hz.

Prompt injury: A medical condition received as a result of the falling debris which requires (or should have required) professional medical attention within 48 hours of the impact.

Solar flux unit (sfu): Equal to 10^4 janskys measured at a wavelength of 10.7 cm.

3.3 Small Satellite Categories

For this document, the following categories of small satellites are used:

Minisatellite (100-500 kg): The term "minisatellite" usually refers to an artificial satellite with a "wet mass" (including fuel) between 100 and 500 kg (220 and 1,100 lb). Minisatellites are usually simpler but use the same technologies as larger satellites.

Microsatellite (10-100 kg): Microsatellite or "microsat" is usually applied to the name of an artificial satellite with a wet mass between 10 and 100 kg (22 and 220 lb).

Nanosatellite (1-10 kg): The term "nanosatellite" or "nanosat" is usually applied to an artificial satellite with a wet mass between 1 and 10 kg (2.2 and 22 lb). CubeSats normally fall within the nanosatellite category.

Picosatellite (0.1-1 kg): Picosatellite or "picosat" (not to be confused with the PicoSat series of microsatellites) is usually applied to the name of an artificial satellite with a wet mass between 0.1 and 1 kg (0.22 and 2.2 lb). Proposed designs of these types can have multiple picosatellites working together or in formation (sometimes the term "swarm" is applied). Some designs require a larger "mother" satellite for communication with ground controllers or for launching and docking with picosatellites.

4. REQUIREMENTS

4.1 Objectives of Orbital Debris Assessments and Planning

- a. It is U.S. and NASA policy to limit the generation of orbital debris, consistent with mission requirements and cost effectiveness. NPR 8715.6 requires that each program or project conduct a formal assessment for the potential to generate orbital debris.
- b. Each program or project should attempt to meet all pertinent requirements for its spacecraft, launch vehicle orbital stage(s), and objects released during nominal operations. It is understood, however, that satisfying these requirements must be balanced with the necessity to meet mission requirements and to control costs. If a requirement cannot be met because of an overriding conflict with mission requirements, technical capabilities, or prohibitive cost impact, then a waiver can be requested through the NASA Program Manager per NPR 8715.3 Section 1.13 with the ODAR containing the appropriate rationale and justification.
- c. The NASA ODPO is staffed and funded to provide support to programs either as an Agency overhead or cost reimbursable function. The SMA organization at each Center and NASA Headquarters can also assist programs and projects with the preparation of the required ODARs and EOMPs.
- d. Paragraph 1.1.3 of this NASA-STD requires that programs/projects use the orbital debris modeling tools provided by the NASA ODPO in assessing orbital debris generation and risk in Earth orbit

4.2 Conducting Debris Assessments: An Overview

The objective of the NASA Orbital Debris Program is to limit the generation of debris in orbit and the risk to human life due to generated orbital debris through prevention and analyses. Debris can damage other spacecraft, provide false scientific readings, and become a hazard to spacecraft, people in orbit, and people on the ground. In addition to limiting generation of debris in Earth orbit, NASA requires that the generation of debris be limited in lunar orbit. NASA should also limit debris generated at the Earth-Sun Lagrange points and in orbit around other celestial bodies.

Limiting orbital debris involves the following:

- Limiting the generation of debris associated with normal space operations;
- Limiting the probability of impact with other objects in orbit;
- Limiting the consequences of impact with existing orbital debris or meteoroids;
- Limiting the debris hazard posed by tether systems;
- Depleting onboard energy sources after completion of mission;
- Limiting orbital lifetime in LEO after mission completion or maneuvering to a disposal orbit; and
- Limiting the human casualty risk from space system components surviving reentry as a result of postmission disposal.

Note: NASA-HDBK 8719.14 serves as a reference document to assist orbital debris practioners and program/project management in understanding orbital debris. Topics in NASA-HDBK 8719.14 include the orbital debris environment, measurements, modeling, shielding, mitigation, and reentry. It is strongly encouraged that the NASA-HDBK be used with the implementation of NPR 8715.6 and NASA-STD 8719.14.

4.2.1 ODA and ODARs

- a. The detailed requirements and evaluation methods for ODARs are presented in Sections 4.3 through 4.8.
- b. The orbital debris assessment covers the following broad areas:
 - The potential for generating debris during normal operations or malfunction conditions;
 - The potential for generating debris from a collision with debris or orbiting space systems;
 - Postmission disposal.
- c. These broad areas are categorized into seven issues that are addressed in the assessment:
 - Debris released during normal operations;
 - Debris generated by explosions and intentional breakups;
 - Debris generated by on-orbit collisions during mission operations;
 - Reliable disposal of spacecraft and launch vehicle orbital stages after mission completion;
 - Structural components impacting the Earth following postmission disposal by atmospheric reentry;
 - Disposal of spacecraft and launch vehicle stages in orbits about the Moon; and
 - Debris generated by on-orbit collisions with a tether system.
- d. The assessment shall be organized in an ODAR using Appendix A, Section A.1 ([Requirement 56371](#)).
- e. ODAs being performed on components or portions of a spacecraft shall document the assessment in the abbreviated ODAR using Appendix A.3 ([Requirement 56372](#)).
- f. It is strongly encouraged that programs limit the regeneration of existing programmatic assessments, but rather include it as an attachment to the ODAR.
- g. NPR 8715.6 specifies the timing of deliveries of ODARs to NASA.
- h. Although the first complete ODAR is not required until PDR, an “Initial ODAR” is required for each project to assist NASA management in considering potential orbital debris issues during concept development (Phase A) and development of preliminary requirements, specifications, and designs (Phase B) to estimate and minimize potential cost impacts.
- i. ODAs being performed on space systems during a project’s Phase A shall document the assessment in the Initial ODAR using Appendix A.4 ([Requirement](#)).

j. NASA programs/projects that are flying as payloads of the International Space Station (ISS), or other crewed spacecraft that remain encapsulated by the spacecraft (i.e., not exposed to outer space environment) are exempted from performing orbital debris assessments. Payloads which are temporarily deployed and retrieved into the ISS or on the same spacecraft flight shall provide an abbreviated Orbital Debris Assessment (ODA) Report (ODAR) per this NASA-STD ([Requirement 56376](#)).

4.2.2 EOMP

An EOMP is developed for limiting debris generation and limiting risk to the public and other active spacecraft during decommissioning, and disposal of all space objects.

- a. The EOMP is a living document. It is developed during the later stages of mission development to ensure that design and operational use do not preclude a safe decommissioning and disposal. The EOMP identifies milestones in the operational life of the mission which affect the EOM processing. After those milestones, the EOMP and the health of the critical items defined in the EOMP should be evaluated and updated so that NASA management understands the constraints and options available at EOM for limiting orbital debris.
- b. The EOMP shall be organized using Appendix B, Section B.1 ([Requirement 56380](#)).
- c. The EOMP contains statements covering what actions must be undertaken in the event of reductions of capabilities or consumables which may significantly and predictably threaten the ability to carry out the planned EOM disposal. This includes reduction of system capability to “single string” unless expressly agreed otherwise.
- d. It is strongly encouraged that programs limit the regeneration of existing programmatic information, but rather include the ODAR and other assessments as attachments.
- e. NPR 8715.6 specifies the timing of deliveries of EOMPs to NASA.
- f. An EOMP may include other aspects of the EOM process (final disposition of data and hardware, for example) if the program finds that the EOMP is the most convenient means of recording this information. Other applicable sections may be placed after the sections specified in Appendix B.

4.2.3 Structure of the Requirements in this Document

- a. Each of Sections 4.3 through 4.8 covers a separate orbital debris technical area. Table 4.2-1 defines the organization for each technical area. Table 4.2-2 lists each orbital debris technical area.

Note: In Table 4.2-1, the ‘4.x’ is a pointer to sections 4.3 to 4.8.

Table 4.2-1: Orbital Debris Technical Area Organization

Section 4.x.1	Definition of the Area
Section 4.x.2	Requirements for the Area
Section 4.x.3	Rationale for the Area Requirements
Section 4.x.4	Methods to Assess Compliance
Section 4.x.5	Brief Summary of Mitigation Measures Used in NASA for this Area

b. The sections titled "Method to Assess Compliance" (Sections 4.x.4) provide detailed steps for how compliance with each requirement is determined and measured. Actual compliance can be verified with the specially designed DAS for operations in Earth orbit. Both the software and its documentation can be downloaded from the Internet at <http://orbitaldebris.jsc.nasa.gov/mitigate/das.html>. NASA ODPO contact personnel are also identified at this web site. The models in DAS support the approach and techniques described in this NASA-STD. If methods or models other than DAS are used, a full description of the models used will need to be added to ODAR Front Matter (See Appendix A, Section A.1).

c. Table 4.2-2 provides a summary of each of the technical requirements which need to be addressed in the ODAR.

Table 4.2-2: Orbital Debris Technical Area Issues and Corresponding Requirements

(Note: Requirement applicability is indicated in the introduction to each requirement area in sections 4.3 – 4.8.)

Debris Assessment Issues	Reqm't	Requirement Summary	Comments
Release of debris during normal mission operations	4.3-1 and 4.3-2	- Limit number and orbital lifetime of debris passing through LEO - Limit lifetime of objects passing near GEO	Requirement includes staging components, deployment hardware, or other objects that are known to be released during normal operations.
Accidental explosions	4.4-1 and 4.4-2	- Limit probability of accidental explosion during mission operations - Passivate to limit probability of accidental explosion after EOM	Requirement addresses systems and components such as range safety systems, pressurized volumes, residual propellants, and batteries.

Debris Assessment Issues	Reqm't	Requirement Summary	Comments
Intentional breakups	4.4-3 and 4.4-4	- Limit number, size, and orbital lifetime of debris larger than 1 mm and 10 cm - Assess risk to other programs for times immediately after a test when the debris cloud contains regions of high debris density	Intentional breakups include tests involving collisions or explosions of flight systems and intentional breakup during space system reentry to reduce the amount of debris reaching the surface of the Earth.
Collisions with large objects during orbital lifetime	4.5-1	Assess probability of collision with intact space systems or large debris (>10cm)	Collisions with intact space systems or large debris may create a large number of debris fragments that pose a risk to other operating spacecraft. A significant probability of collision may necessitate design or operational changes.
Collisions with small debris during mission operations	4.5-2	Assess and limit the probability of damage to critical components as a result of impact with small debris	Damage by small debris impacts can result in failure to perform postmission disposal. A significant probability of damage may necessitate shielding, use of redundant systems, or other design or operational options.
Postmission disposal	4.6-1, 4.6-2, 4.6-3, and 4.6-4	- Remove spacecraft and orbital stages from LEO to reduce collision threat to future space operations - Remove spacecraft and orbital stages from GEO to reduce collision threat to future space operations - Govern intermediate disposal orbits - Assess reliability of postmission disposal - Assess options for disposal beyond Earth's orbit	The accumulation of spacecraft and orbital stages in Earth orbit increases the likelihood of future collisions and debris generation. The orbital lifetimes of spacecraft and orbital stages in LEO and near GEO must be limited. The removal of objects at the EOM is preferred, but specific disposal orbits may be used.

Debris Assessment Issues	Reqm't	Requirement Summary	Comments
Reentry Debris Casualty Risk	4.7-1	Limit number and size of debris fragments that survive atmospheric reentry	This requirement limits human casualty expectation.
Collision risk posed by tether systems	4.8-1	Assess the probability of collision with resident space objects and limit orbital lifetime Mitigate the effects of severed tether systems	Tether systems may pose special collision hazards with other objects in orbit. Severed tethers may create additional hazards and hinder disposal plans.

4.2.4 Deviations to ODARs and EOMPs

Requirements for submission of ODARs and EOMPs are contained in NPR 8715.6. Any deviation/waivers/exceptions from the requirements for ODAR and EOMPs stated in this NASA-STD require NASA management approval per NPR 8715.6.

4.3 Assessment of Debris Released During Normal Operations

Orbital debris analyses assess the amount of launch vehicle and spacecraft debris released in normal operations. This requirement area applies to all space structures while in Earth orbit and is recommended for lunar and Mars orbital operations.

4.3.1 Definition of Released Debris Technical Area

- a. The goal is that in all operational orbits, space systems are designed not to release debris during normal operations. Where this is not feasible, any release of debris needs to be minimized in number, area, and orbital lifetime.
- b. Historically, debris has been released as an incidental part of normal space operations. This type of debris is referred to as operational or mission-related debris and includes such objects as sensor covers, tie-down straps, explosive bolt fragments, attitude control devices, and dual payload attachment fittings. Space systems need to be designed to avoid the creation of any operational or mission-related debris. If the release of debris is unavoidable, the release should be done in a manner that limits the risk to other users of space. Debris 1 mm in diameter (about 1 mg) and larger for LEO and 5 cm (about 100 gm) and larger for GEO is a source of concern because these debris have sufficient energy to critically damage an operating spacecraft. Large debris can create a cloud of secondary debris fragments in the event of a collision with another resident space object.
- c. The probability of a future collision occurring with debris depends on the number and size of the debris and on the length of time the debris remains in orbit. The requirements, therefore, limit the total number of such debris objects and their orbital lifetimes. Debris released during

normal operations includes debris released during launch vehicle staging, payload separation, deployment, mission operations, and EOM passivation/disposal. Spacecraft and spent orbital stages, as intact structures, are not considered operational debris themselves and are addressed later in Sections 4.5 and 4.6.

d. Small debris, such as slag which is ejected during the burning of a solid rocket motor, and liquids dispersed from a spacecraft, are not covered by the requirements of this NASA-STD.

4.3.2 Requirements for the Control of Debris Released During Normal Operations

NASA policy is that all NASA programs and projects assess and limit the amount of debris released as a part of the mission.

4.3.2.1 *Requirement 4.3-1: Debris passing through LEO – released debris with diameters of 1mm or larger:* a. Requirement 4.3-1a: All debris released during the deployment, operation, and disposal phases shall be limited to a maximum orbital lifetime of 25 years from date of release ([Requirement 56398](#)).

b. Requirement 4.3-1b: The total object-time product shall be no larger than 100 object-years per mission ([Requirement 56399](#)). The object-time product is the sum of all debris of the total time spent below 2,000 km altitude during the orbital lifetime of each object. (See section 4.3.4.2 for methods to calculate the object-time product.)

4.3.2.2 *Requirement 4.3-2: Debris passing near GEO:* For missions leaving debris in orbits with the potential of traversing GEO (GEO altitude +/- 200 km and +/- 15 degrees latitude), released debris with diameters of 5 cm or greater shall be left in orbits which will ensure that within 25 years after release the apogee will no longer exceed GEO - 200 km ([Requirement 56400](#)).

4.3.3 Rationale for Released Debris Area Requirements

a. The intent of Requirement 4.3-1 is to remove debris in LEO from the environment in a reasonable period of time. The 25-year removal time from LEO limits the growth of the debris environment over the next 100 years while limiting the cost burden to programs and projects. The limit of 25 years has been thoroughly researched and has been accepted by the U.S. Government and the major space agencies of the world.

b. Debris in orbits with perigee altitudes below 600 km will usually have orbital lifetimes of less than 25 years. This requirement will have the greatest impact on programs and projects with perigee altitudes above 700 km, where objects may remain in orbit naturally for hundreds of years.

c. Requirement 4.3-1b limits the total number of debris objects released while taking into account their orbital lifetimes. Based on historical precedent and practice, an acceptable level of risk for released debris damaging another operational spacecraft is $<10^{-6}$ (over the life of the decay). The value of 100 object-years was chosen because debris released during normal operations following this requirement will have a probability on the order of 10^{-6} of hitting and potentially damaging an average operating spacecraft.

d. Examples of LEO debris are the cover (0.3 kg and $\sim 0.2 \text{ m}^2$) released from the SABER instrument on the TIMED spacecraft which was launched in 2001 and the Delta 2 Dual Payload Attachment Fitting (DPAF) employed on the ICESAT and CHIPSAT mission of 2003. In both cases the debris were left in orbits of less than 630 km and are expected to decay from orbit well within the 25-year requirement.

e. Debris that is not removed from GEO altitude may remain in the GEO environment for many thousands of years. Therefore, Requirement 4.3-2 limits the accumulation of debris at GEO altitudes and will help mitigate the development of a significant debris environment, as currently exists in LEO. The 200 km offset distance takes into account the operational requirements of GEO spacecraft (see Section 4.6). Special orbit propagation models are necessary to evaluate the evolution of disposal orbits to ensure that debris do not later interfere with GEO, as a result of solar and lunar gravitational perturbations and solar radiation pressure.

4.3.4 Methods to Assess Compliance

Compliance to Section 4.3 requirements are documented in the ODAR and EOMP for all items/objects larger than 1 mm in LEO and 5 cm in GEO planned for release during all phases of flight.

4.3.4.1 Debris Passing Through LEO: 25-Year Maximum Lifetime (Requirement 4.3-1a)

a. The amount of time a debris object will remain in orbit depends on its initial orbit, on the area-to-mass ratio of the debris, and on solar activity. For an object with an apogee altitude above 5,000 km, the orbit lifetime will also be affected by lunar and solar gravitational perturbations.

b. The steps in performing the ODA for this requirement are as follows:

(1) Determine the average cross-sectional area, area-to-mass ratio, and initial orbit for each debris piece released. The average cross-sectional area for atmospheric drag calculations for an object that is not stabilized in attitude is the cross-sectional area averaged over all aspect angles and is measured in square meters. The NASA ODPO's DAS provides a rigorous means of determining average cross-sectional area. It can be approximated as follows:

(a) For convex shaped debris, the average cross-sectional area is approximately 1/4 of the surface area. For a convex shape, all of the surface area elements are exposed to a complete hemisphere (2π steradians) of deep space. Examples of convex shapes are spheres, plates, and cylinders.

(b) For non-convex shaped debris, an estimate of the average cross-sectional area may be obtained in two ways:

[1] For nearly convex shaped debris; i.e., debris for which there is almost no shielding of one surface element from the deep space environment by another, use 1/4 of the effective total surface area of the debris. The effective total surface area is the total surface area decreased by the surface area shielded from deep space. Examples of nearly convex shapes are two convex

shapes attached by a connecting element such as a cable or a convex shaped debris object with an appendage.

[2] For complex debris shapes, determine the view, V , that yields the maximum cross-sectional area and denote the cross-sectional area as $A_{\max}$. Let A_1 and A_2 be the cross-sectional areas for the two viewing directions orthogonal to V . Then define the average cross-sectional area as $(A_{\max} + A_1 + A_2) / 2$.

(c) If the debris will assume a stable attitude relative to the velocity vector, the average cross-sectional area for atmospheric drag calculations is the cross-sectional area presented in the direction of motion.

(d) The area-to-mass ratio for the debris object is the average cross-sectional area (m^2) divided by the mass (kg).

(e) The initial debris orbit is the orbit of the object releasing the debris unless the release occurs with Δv greater than 10 meters per second. For debris released with significant Δv (typically greater than 10 meters per second), the initial debris orbit may be significantly different from that of the object releasing the debris. DAS can be used to calculate the initial orbit in this case.

(2) With the debris orbital parameters, area-to-mass ratio, and year of release into orbit, use DAS to determine the orbital lifetime. If the apogee of the debris is greater than 5000 km, then additional orbital data will be needed. DAS will prompt the user for this information. Assistance can also be obtained from the NASA ODPO at the NASA JSC.

4.3.4.2 Debris Passing Through LEO: Total Object-Time Product (Requirement 4.3-1b)

a. The total object-time product is the sum, over all objects, of the orbit dwell time in LEO. “Orbit dwell time” is defined as the total time spent by an orbiting object below an altitude of 2000 km during its orbital lifetime. If the debris is in an orbit with apogee altitude below 2000 km, the orbit dwell time equals the orbital lifetime. The orbit dwell time for each object can be obtained directly using DAS and the orbital information collected for the evaluation of Requirement 4.3-1.

b. If the calculated orbit dwell time for debris is calculated to be 25 years, then no more than four such debris can be released to be compliant with the 100 object-years limit. Note that Requirement 4.3-1a limits the total orbital lifetime of a single piece of debris passing through LEO to 25 years, regardless of how much time per orbit is spent below 2000 km. If the orbital dwell time of the debris is only 20 years, then a total of up to five debris can be released and still satisfy Requirement 4.3-1b, as long as the maximum orbital lifetime of each debris does not exceed 25 years. Figure 4.3-1 depicts the relationship between perigee and apogee altitudes in determining orbital lifetime.

4.3.4.3 Debris Passing Near Geosynchronous Altitude (Requirement 4.3-2)

a. In general, debris passing near GEO can be categorized as in nearly circular or in highly eccentric orbits. An example of the former would be debris released by a spacecraft after the

spacecraft has already been inserted into an orbit near GEO. The GOES 2 spacecraft employed a design of this type. To ensure that the debris is compliant with Requirement 4.3-2, the spacecraft must be sufficiently above or below GEO at the time of debris release. DAS can determine the minimum altitude above GEO or the maximum altitude below GEO to ensure that the debris is not perturbed into GEO within 100 years.

b. Debris may also originate from a launch vehicle orbital stage which has directly inserted its payload into an orbit near GEO; e.g., the IUS upper stage used on the TDRS 7 mission. The goal is that no debris is released and that the orbital stages are sufficiently removed from GEO at the time of debris release to minimize the risk to other GEO objects, as described in the previous paragraph.

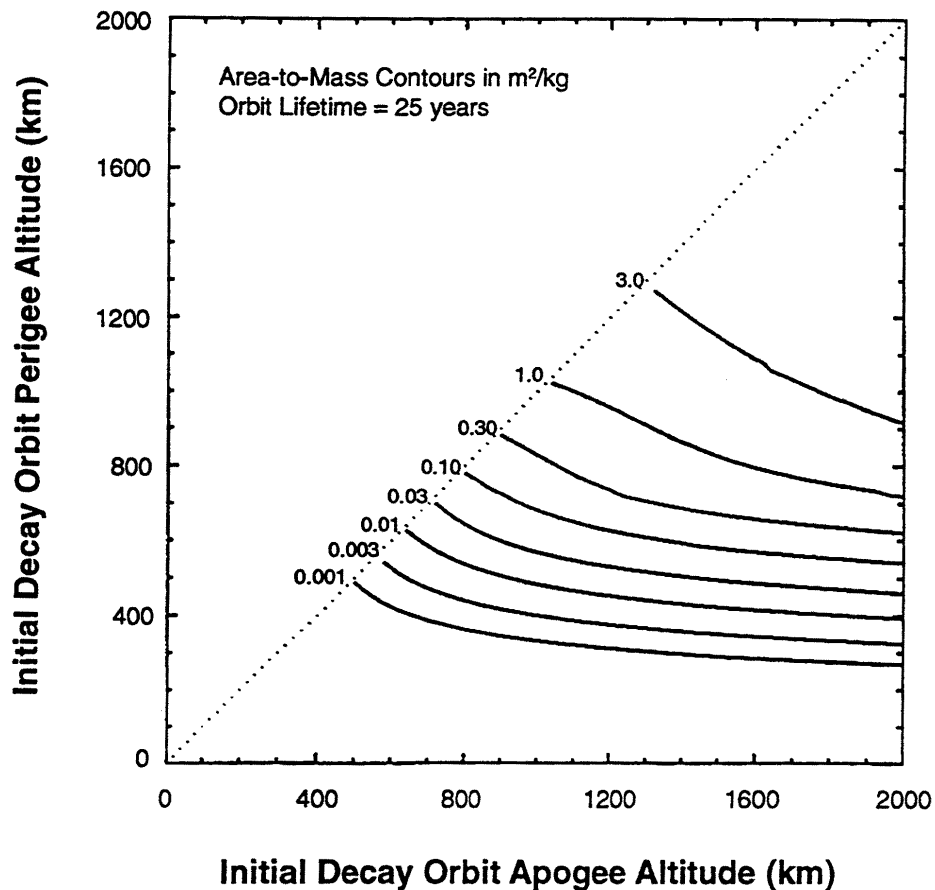


Figure 4.3-1. Maximum orbital parameters for sample area-to-mass values to ensure compliance with 25-year orbital lifetime limit under mean solar activity conditions and neglecting solar radiation effects

c. Debris may also be released into highly eccentric geosynchronous transfer orbits (GTO) with perigees near LEO or at higher altitudes and with apogees near GEO. (For debris with perigees passing through LEO, requirements 4.3-1a and 4.3-1b take precedence.) High perigee GTOs (above 2000 km) have been designed for use on several occasions by Proton launch vehicles and GOES 13. Debris released at the time of payload separation on a mission of this type would fall

under Requirement 4.3-2. Debris can be left in an eccentric orbit traversing GEO, if orbital perturbations will cause the object to leave GEO within 25 years. DAS can be used to determine the long-term orbital perturbation effects for specific initial orbital conditions and, hence, to determine compliance with Requirement 4.3-2 by ensuring the debris will not reenter the GEO region within 100 years.

4.3.5 Brief Summary of Mitigation Measures Used in NASA for this Area

If a program or project does not fall within the above requirements, a number of mitigation measures may be taken. These include:

- Releasing debris in orbits with lower perigee altitude to reduce orbital lifetime;
- Designing debris with larger area-to-mass ratio to reduce orbital lifetime;
- Releasing debris under conditions in which lunar and solar perturbations will reduce lifetime; and
- Limiting release of debris by making design changes, changing operational procedures, or confining debris to prevent release into the environment.

Ground based simulations and testing can be used to better understand the characteristics and confinement approaches.

4.4 Assessment of Debris Generated by Explosions and Intentional Breakups

Orbital debris analyses assess accidental explosion probability and intentional breakups during and after completion of mission operations. Requirements 4.4-1, 4.4-2, and 4.4-3 are required for all space structures in Earth and lunar orbits. Requirement 4.4-3 is recommended for Earth-Sun Lagrange Points, Earth-Moon Lagrange points, and Mars operations.

Section 4.4 is not intended to mandate the use of techniques that could cause unreasonable passivation errors or malfunctions that involve nonreversible passivation methods.

4.4.1 Definition of the Explosion and Intentional Breakup Technical Area

- a. Spacecraft and launch vehicle orbital stage explosions have been the primary contributor to the hazardous orbital debris environment. Some explosions have been accidental with onboard energy sources providing the energy such as residual propellants or pressurants left in orbital stages. However, some intentional breakups have occurred as tests or as a means of disposing of spacecraft.
- b. In order to limit the risk to other space systems from accidental breakups after the completion of mission operations, all onboard sources of stored energy of a space system, such as residual propellants, batteries, high-pressure vessels, self-destructive devices, flywheels, and momentum wheels are depleted or safed when they are no longer required for mission operations or postmission disposal. Depletion should occur as soon as this operation does not pose an unacceptable risk to the payload (see section 4.6.2.5).
- c. Meeting this requirement necessitates reliable designs to prevent explosions during operations as well as after operations are completed.

4.4.1.1 Accidental Explosions

- a. Accidental explosions of spent orbital stages have been the primary source of long-lived debris greater than 1 cm in diameter in LEO. The assessed source of energy for most of these events has been residual propellants, including liquid oxygen and hypergolic propellants. U.S. Delta 1 second stages were a principal source of such debris before corrective measures were implemented, but similar failures have been observed with European, Chinese, Russian, French, Indian, and Ukrainian orbital stages. Such failures have occurred as soon as a few hours and as long as 23 years after launch. The explosion of a 2-year-old Pegasus orbital stage in 1996 produced the greatest number of cataloged fragmentation debris to that date and was probably caused by the failure of a pressure regulation valve connecting a high pressure nitrogen supply with a lower pressure propellant tank. Several spacecraft breakups have been linked to battery failures.
- b. Accidental explosions, primarily related to propulsion system malfunctions, during orbital deployment or orbital operations have also been documented. However, historically these events have attracted greater attention and more extensive preventive measures.

4.4.1.2 Intentional Breakups

- a. Intentional breakups have been used to reduce the amount of debris surviving the reentry of large space structures and in conjunction with on-orbit tests. An example of the latter was the deliberate structural limits testing of the second flight of the Saturn IVB stage in 1966.
- b. An understanding of the approach taken in the evaluation for intentional breakups requires an understanding of the development of a debris cloud after breakup. Immediately after breakup, the debris cloud exhibits large spatial and temporal changes in the concentration of the debris. For example, near the inertial point in the orbit where the breakup occurred there may be no debris at times, while at other times the debris cloud densities may be orders of magnitude above the background. An operating spacecraft may have a small probability of colliding with the debris if the interaction were to occur randomly but a high probability of collision if it passes through a region of high density concentration. The test program can avoid having such high risk interactions by controlling the time and/or location of the test. However, because of the many orbital perturbations which affect space objects and because of the sensitivity of the debris cloud evolution to the exact time and location of the breakup event, the potential risk to other operating spacecraft can be determined accurately only a few days before the test. The assessment and control of this risk must be performed in conjunction with the Department of Defense. This planning process needs to commence no later than 30 days before the planned breakup.
- c. Within a few days after the breakup, the debris becomes more uniformly distributed within the cloud, and the cloud reaches a state called the pseudo-torus. Later, the debris cloud will expand and evolve into a shell distribution. By the time the debris cloud reaches the pseudo-torus state, the probability of collision between the debris cloud and other objects in space can be calculated assuming random encounters.

d. Secondary debris can also be generated by the collision of breakup debris with large operational and non-operational resident space objects. This risk is mitigated by placing limits on the numbers and orbital lifetime of breakup debris large enough to cause significant subsequent breakups.

4.4.2 Requirements for the Area

4.4.2.1 Accidental Explosions

Orbital debris analyses assess the probability of accidental spacecraft and launch vehicle orbital stage explosion during and after completion of deployment and mission operations.

4.4.2.1.1 Requirement 4.4-1: Limiting the risk to other space systems from accidental explosions during deployment and mission operations while in orbit about Earth or the Moon:

For each spacecraft and launch vehicle orbital stage employed for a mission, the program or project shall demonstrate, via failure mode and effects analyses or equivalent analyses, that the integrated probability of explosion for all credible failure modes of each spacecraft and launch vehicle is less than 0.001 (excluding small particle impacts) ([Requirement 56449](#)).

4.4.2.1.2 Requirement 4.4-2: Design for passivation after completion of mission operations while in orbit about Earth or the Moon: Design of all spacecraft and launch vehicle orbital stages shall include the ability and a plan to deplete all onboard sources of stored energy and disconnect all energy generation sources when they are no longer required for mission operations or postmission disposal or control to a level which can not cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft ([Requirement 56450](#)).

4.4.2.2 Intentional Breakups

Orbital debris analyses evaluate the effect of intentional breakups of spacecraft and launch vehicle orbital stages on other users of space.

4.4.2.2.1 Requirement 4.4-3. Limiting the long-term risk to other space systems from planned breakups:

Planned explosions or intentional collisions shall:

- a) Be conducted at an altitude such that for orbital debris fragments larger than 10 cm the object-time product does not exceed 100 object-years ([Requirement 56453](#)). For example, if the debris fragments greater than 10cm decay in the maximum allowed 1 year, a maximum of 100 such fragments can be generated by the breakup.
- b) Not generate debris larger than 1 mm that remains in Earth orbit longer than one year ([Requirement 56454](#)).

4.4.2.2.2 Requirement 4.4-4: Limiting the short-term risk to other space systems from planned breakups: Immediately before a planned explosion or intentional collision, the probability of debris, orbital or ballistic, larger than 1 mm colliding with any operating spacecraft within 24 hours of the breakup shall be verified to not exceed 10^{-6} ([Requirement 56455](#)).

4.4.3 Rationale for the Area Requirements

4.4.3.1 Accidental Explosions

- a. By keeping the probability of accidental explosion less than 0.001, the average probability of an operating spacecraft colliding with an explosion fragment larger than 1 mm from that space system will be less than 10^{-5} per “average spacecraft.” An average spacecraft is a spacecraft of average size with average mission lifetime in circular orbit at an altitude through which explosion debris fragments that are 1 mm or larger would pass if an explosion occurred. The average probability of collision is the probability of collision averaged over the altitude that would be covered by the breakup cloud.
- b. In cases where design and operational modifications have been made to remove stored energy sources, accidental explosions have been prevented. This process is called passivation. Onboard energy sources include chemical energy in the form of propellants (including a cold gas attitude control system), pressurants, explosives associated with range safety systems, pressurized volumes such as in sealed batteries, and kinetic energy devices such as control moment gyroscopes. An analysis should be done of pressurized systems which generally are not susceptible to fragmentation failures and their need to be passivated at EOM to mitigate the potential consequences of a later collision with a high speed object. For example, a cold gas attitude control system usually has a low probability for fragmentation failures, yet this system should still be passivated at EOM. The international adoption of passivation measures for both spacecraft and launch vehicle orbital stages has resulted in a significant curtailment in the rate of growth of the orbital debris population.
- c. Passivation of all energy storage and charging systems should occur as soon as such operation does not pose an unacceptable risk to the mission (see section 4.6.2.5). In LEO, propellant depletion burns are normally designed to reduce the orbital lifetime of the vehicle to the maximum extent possible. Propellant depletion burns and compressed gas releases should also be designed to minimize the probability of accidental collision.

4.4.3.2 Intentional Breakups

- a. These requirements reflect the approach taken within the U.S. space program to limit the debris contribution from on-orbit tests. The P-78 (SOLWIND) ASAT test and the Delta-180 experiment are examples of missions reviewed by a safety panel for their near-term threat to operating spacecraft and for their long-term contribution to the orbital debris environment.
- b. Debris released from an intentional breakup under Requirement 4.4-3 should not be a greater contributor to the long-term growth of the orbital debris environment than any debris released under requirements for normal operations (see Requirement 4.3-1). The limit of 1 year for orbit lifetimes for debris larger than 1 mm prevents the accumulation of debris from intentional breakups.
- c. The risk to other users from concentrations within the debris cloud which occur immediately after breakup is limited by Requirement 4.4-4 to no more than the risk represented by other debris deposition events such as release of operational debris.

4.4.4 Methods to Assess Compliance

Compliance to section 4.4 requirements is documented in the ODAR and EOMP for all phases of flight.

4.4.4.1 Accidental Explosions

4.4.4.1.1 Limiting the Probability of Accidental Explosion (Requirement 4.4-1)

Documentation of the failure mode and effects analysis or some equivalent analysis of the credible failure modes that could lead to accidental explosion and their associated probability is included in the ODAR. Small particle impacts are not being considered here since they will be assessed in Section 4.5. If the probability of accidental explosion exceeds 0.001 for either a spacecraft or orbital stage, design or operational countermeasures will be needed to reduce the probability below the aforementioned limit.

4.4.4.1.2 Eliminating Stored Energy Sources (Requirement 4.4-2)

a. Documentation of the EOM sources or potential sources of stored energy that require passivation, and a plan for passivating these sources at EOM is included in the ODAR. Passivation procedures to be implemented might include;

- Burning residual propellants to depletion;
- Venting propellant lines and tanks;
- Venting pressurized systems;
- Preventing recharging of batteries or other energy storage systems;
- Deactivating range safety systems; and
- De-energizing control moment gyroscopes.

b. Residual propellants and other fluids, such as pressurants, should be depleted as thoroughly as possible, by either depletion burns or venting, to prevent accidental breakups by over pressurization or chemical reaction. Opening fluid vessels and lines to the space environment directly or indirectly at the conclusion of EOM passivation, is one way to reduce the possibility of a later explosion.

c. Depletion burns and ventings should not affect other space systems and should not increase the likelihood of fragmentation.

Examples of potentially dangerous actions include a spin-up of the vehicle or inadvertent mixing of vented hypergolic propellants.

Note: The design of these depletion burns and ventings should minimize the probability of accidental collision with known objects in space.

d. Leak-before-burst tank designs are beneficial but are not sufficient to prevent explosions in all scenarios. Therefore, such tanks should still be depressurized at the end of use. However, pressure vessels with pressure-relief mechanisms do not need to be depressurized if it can be

shown that no plausible scenario exists in which the pressure-relief mechanism would be insufficient.

- e. Small amounts of trapped fluids could remain in tanks or lines after venting or depletion burning. Design and operational procedures should minimize the amount of these trapped fluids.
- f. Sealed heat pipes, batteries, and passive nutation dampers need not be depressurized at EOM.
- g. Disconnecting the electrical power source (typically solar array) from the power distribution system is the preferred form of power system passivation. If this is not possible, batteries should be disconnected from their charging circuits as a secondary option. Electrical loads left connected to a battery can fail, leading to battery recharging if the charging circuit is not disconnected.

Note: Paragraph 5.2.1(2) of the IADC Space Debris Mitigation Guidelines provides the additional direction for batteries: “At the end of operations battery charging lines should be de-activated.”

- h. The removal of electrical energy inputs from rotational energy devices, such as a gyro, is usually sufficient to ensure the timely passivation of these units.
- i. The ODAR and EOMP contain a full description of the passivation actions to be employed for all sources of stored energy and a notional timeline of when the actions take place. This plan identifies all passivation measures to include, at a minimum, spacecraft fuel depletion, propellant venting, disabling of battery charging systems, safing of bus and payloads, and any sources of stored energy that will remain. For example, an orbital stage main propulsion system depletion burn may be scheduled 15 minutes after separation of the payload, followed by a sequenced venting of the propellant and pressurant tanks thereafter.
- j. Self-destruct systems should be designed not to cause unintentional destruction due to inadvertent commands, thermal heating, or radio frequency interference.

4.4.4.2 Intentional Breakups (Requirements 4.4-3 and 4.4-4)

- a. The evaluation procedure for planned space object breakups uses Requirement 4.4-3 for long-term planning conducted during program development and uses Requirement 4.4-4 for near-term planning conducted shortly before the test. The objective of the long-term plan is to understand and control the impact of the test on the space environment in general; that of the near-term plan is to control the risk of damage to operating spacecraft.
- b. The steps for performing the evaluation are as follows:
 - (1) Define a breakup model for the test. A breakup model describes the debris created in the breakup process in terms of the distributions in size, mass, area-to-mass ratio, and velocity imparted at breakup. A standard breakup model used for debris environment evolution calculations may be acceptable for a test, or the breakup model may require taking into account specific characteristics of the planned test. Standard breakup models or support for defining

specific breakup models for a given test may be obtained from the NASA ODPO at the NASA JSC.

(2) Calculate and sum the object-time products for the debris as derived from the breakup model and the state vector at the time of breakup. This procedure is described in detail in Section 4.3.3. DAS may be used to calculate initial state vectors for the debris fragments and the resulting orbit lifetimes, although use of a special model may be beneficial due to the large number of debris to be evaluated. Compare these summed products with the requirement of 100 object-years.

(3) Verify that no debris larger than 1 mm will have an orbital lifetime greater than one year.

(4) No later than 30 days prior to the planned breakup, coordinate with the Department of Defense (specifically, U.S. Strategic Command) to verify that immediately after the breakup no operating spacecraft will have a probability of collision greater than 10^{-6} with debris larger than 1 mm. Special software is generally required to analyze the debris cloud characteristics immediately after breakup. Contact the NASA ODPO at NASA JSC for assistance.

4.4.5 Brief Summary of Mitigation Measures Used in NASA for this Area

To lower the risk associated with on-orbit breakups:

- Lower the altitude at which the breakup occurs. This is by far the most effective response for reducing both the near-term and long-term risk to other users of space.
- Lower the perigee altitude of the orbit of the breakup vehicle(s); and/or
- Adjust the time for performing the breakup to avoid spacecraft or large resident space object interactions with regions of high flux concentration.
- Deplete propellants and other stored energy sources as soon as practical.

4.5 Assessment of Debris Generated by On-orbit Collisions

Orbital debris analyses assess the ability of the design and mission profile of a space system to limit the probability of accidental collision with known resident space objects during the system's orbital lifetime. Requirement area 4.5 applies for all space structures in Earth and lunar orbits.

4.5.1 Definition of the Collision-induced Risk to Disposal Technical Area

a. Debris can be generated by random on-orbit collisions during and after mission operations. At issue are both the direct generation of debris by collision between the space vehicle and another large object in orbit and the indirect or potential generation of debris when collision with small debris damages the vehicle to prevent its disposal at EOM, making it more likely that the vehicle will be fragmented in a subsequent breakup.

b. While it remains intact, a spacecraft or launch vehicle orbital stage represents a small collision risk to other users of space; however, once it is fragmented by collision, the collision fragments present a risk to other users that may be orders of magnitude larger. Because of typically high collision velocities, debris objects much smaller than the spacecraft may cause severe fragmentation (referred to as a catastrophic collision). For purposes of evaluation, debris with a diameter of 10 cm and larger will be assumed to cause a catastrophic collision.

c. Catastrophic collisions during mission operations represent a direct source of debris, and the probability of this occurring is addressed by Requirement 4.5-1. However, if a spacecraft or launch vehicle orbital stage fails to perform its planned postmission disposal operations, it becomes a potential source of debris because a structure that is abandoned in orbit can subsequently experience catastrophic breakup by collision or explosion. The probability of such an event occurring as a result of a prior damaging impact with small debris is addressed by Requirement 4.5-2.

4.5.2 Requirements for the Collision-induced Risk to Disposal Area

NASA programs and projects assess and limit the probability that the operating space system becomes a source of debris if it collides with orbital debris or meteoroids.

4.5.2.1 Requirement 4.5-1. Limiting debris generated by collisions with large objects when operating in Earth orbit: For each spacecraft and launch vehicle orbital stage in or passing through LEO, the program or project shall demonstrate that, during the orbital lifetime of each spacecraft and orbital stage, the probability of accidental collision with space objects larger than 10 cm in diameter is less than 0.001 ([Requirement 56506](#)).

4.5.2.2 Requirement 4.5-2. Limiting debris generated by collisions with small objects when operating in Earth or lunar orbit: For each spacecraft, the program or project shall demonstrate that, during the mission of the spacecraft, the probability of accidental collision with orbital debris and meteoroids sufficient to prevent compliance with the applicable postmission disposal requirements is less than 0.01 ([Requirement 56507](#)).

4.5.3 Rationale for the Collision-induced Risk to Disposal Area Requirements

a. Requirement 4.5-1 limits the amount of debris that will be created by collisions between spacecraft or launch vehicle orbital stages in or passing through LEO and other large objects in orbit. By keeping the probability of collision between a spacecraft or orbital stage and other large objects to less than 0.001, the average probability of an operating spacecraft colliding with collision fragments larger than 1 mm from that spacecraft or orbital stage will be less than 10^{-6} per “average spacecraft.” An average spacecraft is a spacecraft of average size with average mission lifetime in circular orbit at an altitude through which the fragments from such a collision would pass if the collision occurred. The average collision probability is the probability of collision averaged over the altitude that would be covered by the breakup cloud. Due to the exceptionally long orbital lifetimes of spacecraft and orbital stages in orbits near GEO, the disposal orbit constraints in section 4.6 limit, to the greatest practical extent, the probability of collision with other large objects.

b. Requirement 4.5-2 limits the probability of spacecraft being disabled and left in orbit at EOM, which would contribute to the long-term growth of the orbital debris environment by subsequent collision or explosion fragmentation. Due to the very short mission durations of some launch vehicle orbital stages, the probability of a disabling small debris impact on orbital stages is not significant.

4.5.4 Methods to Assess Compliance

Compliance to section 4.5 requirements is documented in the ODAR and EOMP for all phases of flight including the launch phase per applicability in Section 4.5 introduction.

The analyses documented in the ODAR and EOMP need to include not only collisions that produce large amounts of debris, but also collisions that will terminate a spacecraft's capability to perform postmission disposal. This documentation should also address methods being used to reduce risk such as mission re-selection or operational collision avoidance and any trade-offs between cost, mission requirements, and risk reduction for each method.

4.5.4.1 Collisions with Large Objects During Orbital Lifetime (Requirement 4.5-1)

a. For missions in or passing through LEO, the probability of a space system being hit by an intact structure or large debris object during its orbital lifetime, P , can be approximated by*

$$P = F * A * T \quad (4.5-1)$$

where

F = weighted cross-sectional area flux for the orbital debris environment exposure

A = average cross-sectional area for the space system in m^2

T = orbital lifetime in years

b. The weighted cross-sectional area flux is derived by evaluating the amount of time the vehicle spends in different altitudes during its orbital lifetime. This value is determined by DAS given the initial orbit, area-to-mass ratio, and the launch date of the vehicle. If the vehicle is maintained at a specific altitude during its mission and/or maneuvers to a different orbit for disposal at EOM, the probability of collision with large objects must be evaluated separately for the different orbits and then summed.

c. The average cross-sectional area is the cross-sectional area averaged over all aspects. For a simple convex space system, it is approximately 1/4 of the surface area. A simple convex spacecraft body with solar panel wings may be given an average cross-sectional area that is 1/4 of the sum of the surface area of the spacecraft body plus solar panels.

d. For highly irregular spacecraft shapes, an estimate of the average cross-sectional area may be obtained as follows: determine the view, V , that yields the maximum cross-sectional area and denote the cross-sectional area as A_{max} . Let A_1 and A_2 be the cross-sectional areas for the two viewing directions orthogonal to V . Then define the average cross-sectional area as $(A_{max} + A_1 + A_2) / 2$.

* The exact expression for this probability is $P = 1 - e^{-FAT}$, which is approximated by Equation 4.5-1 when the product $F \times A \times T$ is less than 0.1

4.5.4.2 Collisions with Small Debris During Mission Operations (Requirement 4.5-2)

a. An impact with small (millimeter to centimeter or milligram to gram) meteoroids or orbital debris can cause considerable damage because the impacts usually occur at high velocity (~10 km/sec for debris, ~20 km/sec for meteoroids). An obvious failure mode caused by orbital debris or meteoroid impact is for the impact to puncture a propellant tank, causing leakage. Other failure modes include the loss of a critical attitude control sensor or a break in an electrical line.

b. Spacecraft design will consider and, consistent with cost effectiveness, limit the probability that collisions with debris smaller than 10 cm diameter will cause loss of control to prevent postmission disposal.

c. For this requirement, only subsystems which are vital to completing post mission disposal need to be addressed. This includes components needed for either controlled reentry, transfer to a disposal orbit, or spacecraft passivation. However, the same methodology can be used to evaluate the vulnerability of the spacecraft instruments and mission-related hardware. This information can be used to verify the reliability of the mission with respect to orbital debris and meteoroid hazards.

d. Determining the vulnerability of a space system to impact with orbital debris or meteoroids can be a very complex process, in some cases requiring hypervelocity impact testing of components and materials that have been designed into the system. The objective of the following evaluation process is to help the user determine (1) if there may be a significant vulnerability to meteoroid or orbital debris impact, (2) which components are likely to be the most vulnerable, and (3) what simple design changes may be made to reduce vulnerability. DAS can provide valuable insight into these issues. If necessary, higher fidelity assessments, such as with the NASA BUMPER II model, may be warranted. The NASA ODPO can assist programs or projects with any questions in this area.

e. For operations in Earth orbit, paragraph 1.1.3 requires that DAS is to be used to determine whether damaging impacts by small particles could reasonably prevent successful post mission disposal operations.

(1) The software estimates the probability that meteoroid or orbital debris impacts will cause components critical to postmission disposal to fail. If this estimate shows that there is a 'significant' probability of failure, a higher-fidelity analysis is needed to guide any redesign and to validate any shielding design.

(2) DAS is not intended to be used to design shielding.

f. To estimate the probability that impacts with small meteoroids or orbital debris will prevent postmission disposal, the project will need to perform the following in order to provide necessary inputs into DAS:

(1) Identify the components critical for postmission disposal and the surface of the component that, when damaged by impact, will cause the component to fail. This surface is termed the "critical surface." Examples of critical components include propellant lines and propellant tanks,

elements of the attitude control system and down-link communication system, batteries, and electrical power lines.

(2) Calculate the at-risk surface area for the critical surface of each critical component.

(a) To calculate the at-risk area for a critical surface, first determine those parts of the critical surface that will be the predominant contributor to failure. Those will likely be the parts that have the least protection from meteoroid or orbital debris impact and may be considered in two cases. In the case where the critical surface is equally protected by other spacecraft components, no part of the surface is the major contributor, and the at-risk area is the total area of the critical surface. In the case where some parts of the critical surface are less protected from impact than other parts, the at-risk area is the surface area of those parts of the critical surface most exposed to space.

(b) For example, if an electronics box is attached to the inside of the outer wall of the vehicle, the at-risk area will be the area of the box on the side attached to the outer wall. If the electronics box is attached to the exterior of the outer wall of the vehicle, the at-risk area will be the total area of the box, excluding the side attached to the outer wall.

(c) The area at risk is then corrected to give an average cross-sectional area at risk, depending on the orientation of the surface with respect to the spacecraft orientation. To perform this correction in DAS, the user will need to input the spacecraft orientation and the unit normal vector to the critical surface. Please consult the DAS users guide for more detail on how to define spacecraft orientation and surface vectors.

(3) For each at-risk surface element, identify vehicle components and structural materials between the surface and space that will help protect that surface. Other vehicle components and structural materials between a critical surface and the meteoroid/debris environment will shield the surface. Determine the material density and estimate the thickness of each layer of material acting as a shield in the direction where there is least material to act as a shield. DAS will independently model each layer of material based upon the user-defined characteristics of each layer and determine an overall risk for each critical surface.

(4) DAS will then calculate the expected number of incidents for failure of postmission disposal critical elements, F_c , by summing the expected number of failures for each critical surface, h_i , as determined by DAS. This sum is expressed as

$$F_c = \sum h_i \quad (4.5-2)$$

(5) DAS calculates the probability of failure of one or more critical elements, P_c , as a result of impact with debris by

$$P_c = 1 - e^{-F_c} \approx F_c \quad (4.5-3)$$

where the approximation in the last step is valid if $F_c \leq 0.1$.

4.5.5 Brief Summary of Mitigation Measures Used in NASA for this Area

a. If a spacecraft or orbital stage in LEO or passing through LEO has a high probability of colliding with large objects during its orbital lifetime, there are several mitigation measures that may be taken. These include:

- Changing the planned mission orbit altitude to reduce the expected collision probability;
- Changing the spacecraft design to reduce cross-sectional area and thereby reduce the expected collision probability; and
- Reducing the amount of time in orbit by selecting a lower disposal orbit.

b. There are many mitigation measures to reduce the probability that collisions with small debris will disable the spacecraft and prevent successful postmission disposal. These measures use the fact that the debris threat is directional (for orbital debris, highly directional) and that the directional distribution can be predicted with confidence. Design responses to reduce failure probability include addition of component and/or structural shielding, rearrangement of components to let less sensitive components shield more sensitive components, use of redundant components or systems, and compartmentalizing to confine damage. Since there are many alternatives to pursue for reducing vulnerability to impact with small debris, some of them requiring in-depth familiarity with hypervelocity impact effects, they will not be discussed further in this document. If a significant reduction in failure probability is required, it is advisable to contact the NASA ODPO at the NASA JSC.

4.6 Postmission Disposal of Space Structures

Spacecraft disposal can be accomplished by one of three methods:

- Atmospheric reentry,
- Maneuvering to a storage orbit, or
- Direct retrieval.

Requirement area 4.6 applies as follows:

- a) Requirements 4.6-1, 4.6-2, and 4.6-3 for all space structures when in Earth orbit.
- b) Requirement 4.6-4 for all space structure in orbit about the Earth.
- c) Requirement 4.6-5 for all space structures in orbit about the Earth and the Moon.

4.6.1 Definition of the Postmission Disposal Technical Area

a. The historical practice of abandoning spacecraft and upper stages at EOM has allowed more than 2 million kg of debris to accumulate in LEO. A similar amount of mass now resides in GEO. If the growth of debris mass continues, collisions between these objects will eventually become a major source of small debris, posing a threat to space operations. The most effective means for preventing future collisions is the removal of all spacecraft and upper stages from the environment in a timely manner. These requirements represent an effective method for controlling the growth of the orbital debris environment, while taking into account cost and mission consequences to future programs.

- b. The postmission disposal options are (1) natural or directed reentry into the atmosphere within a specified time frame, (2) maneuver to one of a set of disposal regions in which the space structures will pose little threat to future space operations, and (3) retrieval and return to Earth. The last option requires use of the Space Shuttle or similar vehicle and will generally not be an option, due to logistical constraints, cost, and crew safety.
- c. In general, the most energy-efficient means for disposal of space structures in orbits below 1400 km is via maneuver to an orbit from which natural decay will occur within 25 years of EOM and 30 years from launch. For space structures in orbits between 1400 km and 2000 km, a maneuver to a storage orbit above 2000 km would likely be the best disposal option. Spacecraft and orbital stages in orbits near GEO are disposed of in super-synchronous disposal orbits with a minimum perigee based upon the vehicle characteristics, but typically about 300 km (~185 mi) above GEO.
- d. Special disposal maneuvers are normally not required in Medium Earth Orbit (MEO), although efforts should be made to avoid potential interference with known operational satellite constellations, especially the Global Positioning System.
- e. The space structure disposal requirements in this section are consistent with the recommendations of the Inter-Agency Space Debris Coordination Committee (IADC), the U.S. Government Orbital Debris Mitigation Standard Practices, the International Telecommunications Union (ITU), the U.S. Federal Communications Commission (FCC), and other international and foreign organizations.
- f. NASA space programs and projects shall plan for the disposal of spacecraft and launch vehicle orbital stages and space structures at the end of their respective missions (Requirement).
- g. Postmission disposal shall be used to remove a space structure from Earth orbit in a timely manner or to leave a space structure in a disposal orbit where the structure will pose as small a threat as practical to other space systems (Requirement).
- h. Because of fuel gauging uncertainties near the EOM, a program is recommended to implement a maneuver strategy that reduces the risk of leaving the structure near an operational orbit.

4.6.2 Requirements for the Area

4.6.2.1 *Requirement 4.6-1. Disposal for space structures in or passing through LEO:* A spacecraft or orbital stage with a perigee altitude below 2,000 km shall be disposed of by one of the following three methods: ([Requirement 56557](#))

- a. Atmospheric reentry option:
- Leave the space structure in an orbit in which natural forces will lead to atmospheric reentry within 25 years after the completion of mission but no more than 30 years after launch; or
 - Maneuver the space structure into a controlled de-orbit trajectory as soon as practical after completion of mission.

- b. Storage orbit option: Maneuver the space structure into an orbit with perigee altitude greater than 2000 km and apogee less than GEO - 500 km.
- c. Direct retrieval: Retrieve the space structure and remove it from orbit within 10 years after completion of mission.

4.6.2.2 Requirement 4.6-2. Disposal for space structures near GEO: A spacecraft or orbital stage in an orbit near GEO shall be maneuvered at EOM to a disposal orbit above GEO with a predicted minimum perigee of GEO +200 km (35,986 km) or below GEO with an apogee of GEO - 200 km (35,586 km) for a period of at least 100 years after disposal ([Requirement 56563](#)).

4.6.2.3 Requirement 4.6-3. Disposal for space structures between LEO and GEO:

- a) A spacecraft or orbital stage shall be left in an orbit with a perigee greater than 2000 km above the Earth's surface and apogee less than 500 km below GEO ([Requirement 56565](#)).
- b) A spacecraft or orbital stage shall not use nearly circular disposal orbits near regions of high value operational space structures, such as between 19,200 km and 20,700 km ([Requirement 56566](#)).

4.6.2.4 Requirement 4.6-4. Reliability of postmission disposal operations in Earth orbit: NASA space programs and projects shall ensure that all post mission disposal operations to meet Requirements 4.6-1, 4.6-2, and/or 4.6-3 are designed for a probability of success as follows: ([Requirement 56567](#))

- a. Be no less than 0.90 at EOM.
- b. For controlled reentry, the probability of success at the time of reentry burn must be sufficiently high so as not to cause a violation of Requirement 4.7-1 pertaining to limiting the risk of human casualty.

4.6.3 Rationale for the Area Requirements

- a. The intent of Requirement 4.6-1a is to remove spacecraft and orbital stages in LEO from the environment in a reasonable period of time. The 25-year removal time from LEO limits the growth of the debris environment over the next 100 years, while limiting the cost burden to LEO programs. The 30-year limit recognizes a mean mission lifetime in LEO of five years. Missions with longer anticipated durations should plan on using disposal orbit lifetimes of less than 25 years. Spacecraft and orbital stages in mission orbits with mean altitudes below 600 km will usually have orbital lifetimes less than 25 years and will likely, therefore, automatically satisfy this requirement. This requirement will have the greatest impact on programs with mission orbit perigee altitudes above 700 km, where objects can remain in orbit for hundreds of years if abandoned at EOM.
- b. The 25-year criterion of Requirement 4.6-1a is a maximum value, and, if possible, spacecraft and orbital stages use all available capabilities to minimize the time spent in LEO disposal orbits. For example, orbital stages have often used residual propellants to reduce orbital lifetimes to very short periods, only months or a few years.

c. In general, an elliptical disposal orbit offers the best solution for minimizing energy requirements and minimizing orbital lifetime. For example, if a space structure is in a sun-synchronous orbit (SSO) of 800 km (~495 mi), less energy is required to ensure an orbital lifetime of less than 25 years if the space structure is left in an elliptical rather than a circular orbit. In some cases, the perigee of the disposal orbit will be within the orbital altitudes used for human space flight operations. Orbits less than 400 km are considered as in the orbital altitude of the ISS. However, this poses no risk to human space flight since the space structure will be monitored throughout its orbital lifetime by the U.S. Space Surveillance Network, and established collision avoidance procedures for human space flight will prevent any future collision potential. The vast majority of space objects decaying down through the lower portions of LEO never pose an actual threat to human space flight operations. Elliptical orbits also usually result in a lower integrated risk to human space flight than decaying circular orbits.

d. If disposal by controlled reentry into the atmosphere is chosen, the trajectory must be designed to ensure that the space structure does not skip in the upper regions of the atmosphere. Therefore, the effective perigee of the reentry trajectory should be no higher than 50 km. See Section 4.7 for additional guidance on controlled reentries.

e. In Requirement 4.6-1c only 10 years is allowed for planned retrieval after completion of the mission, which is shorter than the 25 years for orbital decay and atmospheric reentry in Requirement 4.6-1a. Retrieval may leave the space system in a higher altitude orbit where, in general, there is a higher probability per unit time that the system will be involved in a collision fragmentation, whereas transfer to an orbit with reduced lifetime lowers the perigee of the final orbit and reduces the probability per unit time that the system will be a source of collision fragments. To balance the risk of the system creating collision debris, the allowed period of time is therefore less for a system waiting to be retrieved.

f. Spacecraft that have terminated their mission should be maneuvered far enough away from GEO so as not to cause interference with space systems still in geostationary orbit. See Requirements 4.6-2 and 4.6-3.

f.1 Requirement 4.6-3 requires that the minimum increase in perigee altitude at the end of re-orbiting does not come within GEO + 200 km for the next 100 years. A selected perigee of $\text{GEO} + 235 \text{ km} + (1000 \cdot \text{CR} \cdot \text{A}/\text{m})$ and an eccentricity of less than 0.003 ($e < 0.003$) will ensure that the space structure does not come within 200 km of GEO altitude (35,786 km) for at least 100 years (Figure 4.6-1). [CR = solar radiation pressure coefficient, typical values: 1.2-1.5, A = Area in m^2 , and m = mass in kg; the factors 1000 and Cr have hidden units to ensure that the second term yields a value in km.]

g. The propulsion system for a GEO spacecraft should be designed not to be separated from the spacecraft. If there are unavoidable reasons that require separation, the propulsion system must conform to requirement 4.6-3 outside of the protected geosynchronous region (GEO altitude $\pm 200 \text{ km}$).

g.1. Regardless of whether it is separated or not, a propulsion system must be designed for passivation in accordance with Requirement 4.6-5.

h. In 1997 the IADC, whose members represent the world's major space agencies, completed a detailed study of GEO with an objective of developing a requirements-based recommendation for the disposal of space structures near GEO. The IADC concluded that a region within 200 km of GEO be preserved for the operation and relocation of GEO spacecraft. To ensure that disposed spacecraft and orbital stages do not stray into this region at a future date due to the perturbative effects of solar radiation pressure and solar and lunar gravitation, a formula was developed to determine the minimum distance above GEO for disposal orbits. The results are presented in Figure 4.6-1. This formula has been adopted by the FCC and the ITU.

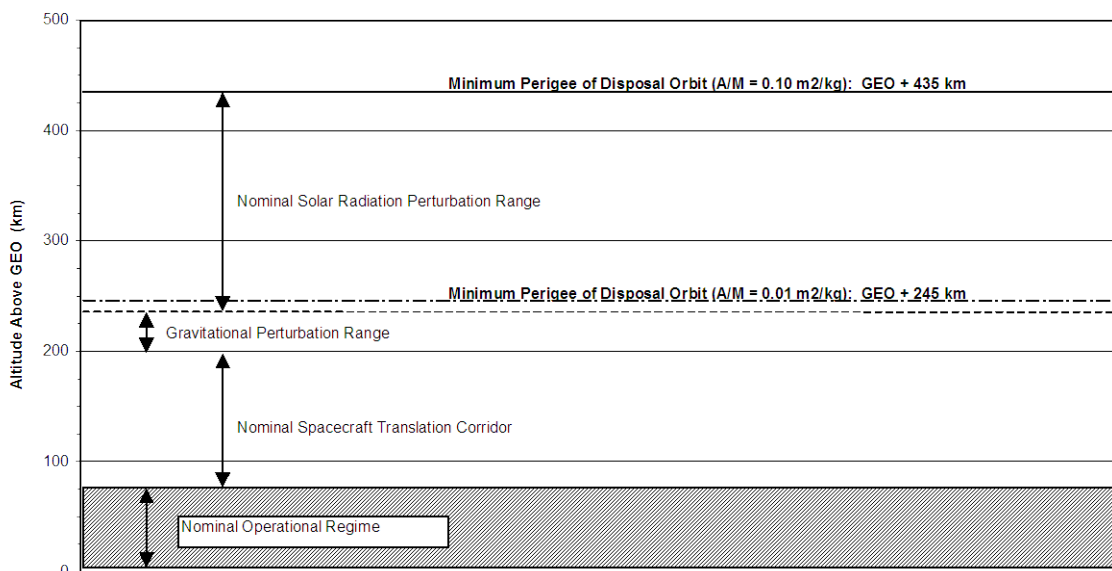


Figure 4.6-1: IADC Rationale for GEO minimum perigee equation

i. Recent studies have also indicated that disposal orbits with modest eccentricities near GEO can be perturbed over long periods into more elliptical orbits with perigees less than 200 km above GEO. Therefore, the initial eccentricity of a GEO disposal orbit should be less than 0.003. In selecting a disposal orbit, the specific initial orbital conditions can be evaluated to determine the long-term perturbative effects and consequent limitations on initial eccentricity.

j. Due to the relatively (compared with LEO) small amount of propellants needed to perform disposal maneuvers near GEO, propellant gauging issues can be important. An adequate amount of propellant needs to be held in reserve to ensure that the desired disposal orbit is reached, usually through a series of maneuvers as defined in the EOMP. This is even more important when orbits of very low eccentricity are needed. In accordance with Requirement 4.4-2, all propellants remaining after achieving the proper disposal orbit need to be vented or burned in a way that does not upset the disposal orbit.

k. From Requirement 4.6-3, disposal orbits between LEO and GEO need to have perigee altitudes above 2000 km. Objects in these orbits will have a low probability of collision (the current rate is less than 1 per 1000 years). If a collision does occur, then very little debris from that collision would come low enough to pose a significant threat to operational spacecraft in

LEO since the region from 1500 km to 2000 km is little used. This disposal option will usually only be attractive for LEO spacecraft and orbital stages in orbits between 1400 km and 2000 km at EOM; at lower altitudes disposal orbits with orbital lifetimes of less than 25 years would be more cost-effective. Since missions between 1400 km and 2000 km are currently rare, the selection of this disposal option is infrequent.

l. Disposal orbits between LEO and GEO are also permitted for space structures in highly elliptical orbits like geosynchronous transfer orbits (GTO), but for most spacecraft and orbital stages in such orbits the use of a perigee-lowering maneuver or of natural perturbations to ensure an orbital lifetime of less than 25 years is more cost-effective than raising perigee to 2000 km. Disposal orbits between LEO and GEO strive to avoid potential interference with major satellite constellations, such as GPS. However, disposal orbits can briefly transit the altitude of such constellations during each revolution. For example, an orbital stage in a disposal orbit of 2500 km by 35,000 km at an inclination of 28.5 deg will regularly pass through the GPS altitude near 20,200 km but the potential for collision will be slight due to the very short dwell time in this region. Decommissioned spacecraft and orbital stages in nearly circular orbits need to avoid the region of 19,700 km to 20,700 km, which is +/- 500 km of semi-synchronous altitude.

m. When selecting a disposal orbit between LEO and GEO, a long-term (at least 100-year) orbital perturbation analysis is conducted (and documented in the ODAR/EOMP) to ensure that the disposal orbit is not altered, particularly by solar and lunar gravitational forces, in such a way that the disposed space structure will later penetrate LEO or GEO. Even nearly circular orbits in MEO can, under certain initial conditions, later experience severe changes in eccentricity, resulting in perigees within LEO or apogees within GEO.

n. Failure to execute a planned disposal maneuver or operation may further aggravate the orbital debris environment. For example, studies have shown that failure to satisfy Requirement 4.6-1 on a routine basis will result in a more rapid increase in the orbital debris population, which in turn will lead to on-orbit collisions producing even more debris. In addition, if a planned maneuver cannot be performed, a risk of vehicle explosion may be created from the unused propellants. Therefore, to satisfy Requirement 4.6-1, the space structure needs to be removed from used orbits to mitigate future collisions. For postmission disposal operations leading to a natural decay within 25 years or to a long-term storage orbit, the probability of success will be no less than 0.90. If a controlled deorbit is planned, the probability of success needs to be sufficiently high so as not to cause a violation of Requirement 4.7-1, which states the risk of human casualty from surviving debris not be less than 1:10,000.

o. All planned postmission maneuvers, including large, discrete maneuvers and continuous low-thrust maneuvers, the NASA operator shall evaluate potential collision risks with other resident space objects with the support of the U.S. Space Surveillance Network ([Requirement 56591](#)).

p. If drag enhancement devices are planned to reduce the orbit lifetime, the ODAR will need to document that such devices will significantly reduce the collision risk of the system or will not cause spacecraft or large debris to fragment if a collision occurs while the system is decaying from orbit.

q. Due to the communication delays caused by extreme distances to Mars and other extraterrestrial bodies, NASA must be expeditious in its consideration of disposal orbits so as to not interfere with future missions to that body.

4.6.4 Methods to Assess Compliance

4.6.4.1 Limiting Orbit Lifetime Using Atmospheric Drag (Requirement 4.6-1a)

a. The amount of time a space structure will remain in orbit depends on its orbit, on the final area-to-mass ratio of the space structure, and on solar activity. For an orbit with apogee altitude above 5,000 km, the orbital lifetime will also be affected by lunar and solar gravitational perturbations. Follow the directions in Section 4.3 of this NASA-STD and in DAS to determine the optimum disposal orbit to satisfy Requirement 4.6-1a. Assistance is also available from the NASA ODPO at JSC.

b. Drag augmentation devices, such as inflatable balloons, increase the area-to-mass ratio of a space structure and, consequently, reduce its orbital lifetime. However, the use of such a device results in a larger collision cross-section, thereby increasing the probability of a collision during natural orbital decay. The increased collision probability should be documented in the ODAR/EOMP. This assessment needs to include the probable consequence of a hypervelocity impact between a resident space object, operational or non-operational, and the drag augmentation device.

c. Space structures using atmospheric drag and reentry for postmission disposal need to be evaluated for survival of structural fragments to the surface of the Earth. The requirement for this evaluation is presented in Section 4.7 of this NASA-STD.

d. A general plan for performing all postmission disposal maneuvers is included in the ODAR/EOMP. Coordination with the U.S. Space Surveillance Network prior to executing these maneuvers at EOM is required.

4.6.4.2 Other Postmission Disposal Options (Requirements 4.6-1b, 4.6-2 and 4.6-3)

Disposal options resulting in the space structure being left in long-lifetime orbits that will limit interference with future space operations are described in Requirements 4.6-1b, 4.6-2, and 4.6-3. DAS can be used to help design disposal orbits in accordance with Requirements 4.6-1b and 4.6-3. Whenever possible, disposal orbits should avoid the creation of an orbital debris concentration (aka: graveyard). Between LEO and GEO, disposal orbits need to be chosen to reduce potential interference with operational satellite constellations. Long-term analysis of orbital stability for the selection of disposal orbit parameters needs to be documented in the EOMP. DAS will measure compliance with Requirement 4.6-3 by evaluating whether or not the orbit will reenter the GEO - 500 km within 100 years from EOM. As noted earlier in this Chapter, propellant gauging is an issue of particular importance for space structures in orbits near GEO.

4.6.4.3 Reliability of Postmission Disposal Operations (Requirement 4.6-4)

Compliance with Requirement 4.6-4 will be evaluated independent of DAS, and is based on ensuring that the structure is able to be removed from protected orbit regions in a timely manner. The debris assessment includes two areas: (1) design or component failure which leads to loss of control during the mission and (2) failure of the postmission disposal system, including insufficient propellant to complete the disposal operation. Conventional failure modes and effects analysis or equivalent analysis are normally used to assess failures which could lead to loss of control during mission operations and postmission disposal. Note that the total reliability for postmission disposal operations not involving directed reentry is 0.90, while the probability of postmission disposal failure due only to small object impacts is 0.01 (Requirement 4.5-2). The probability of failure due to small object impacts and the probability of failure of passivation need not be included in the 0.90 reliability determination. For controlled reentry, the probability of failure of the reentry maneuver will be multiplied by the human casualty risk to determine compliance with Requirement 4.7-1. No specific reliability benchmark for controlled reentry needs to be met for Requirement 4.6-4.

4.6.4.4 Development of an EOMP (Requirement 4.6-5)

- a. Compliance with Requirement 4.6-5 will be based on the completeness of the document with regards to the data required per Appendix B.
- b. The ODARs are considered as design documents and are basically final when the mission is launched. The EOMP is considered as an operational document and will need to be updated periodically until it is implemented at EOM.
- c. As a living document, the EOMP will need to identify events/milestones in the operational life of the mission which affect the end of the mission processing. Those events/milestones include:
 - Any event affecting the reliability of the spacecraft or launch vehicle control systems. This includes the vehicles ability to maintain a safe/controllable attitude and flight path such as reliance on flywheels, solar arrays, and flight control computers.
 - Any event affecting the reliability of the systems needed to passivate the vehicle upon decommissioning such as thrusters required to deplete fuel.
 - Any event affecting the reliability of critical instruments to collect science. For example: the primary mission is photography and when the camera fails, the spacecraft can be decommissioned.
 - Budgetary timelines/milestones.
- d. An EOMP is required for all spacecraft being launched. For spacecraft operating in orbits around Earth, and Earth's moon, a full EOMP is required and updated periodically during the mission per Appendix B. For all other spacecraft, an abbreviated EOMP is required as a minimum per Appendix B.
- e. EOMPs are not considered as complete until they are reviewed and signed by the sponsoring Mission Directorate Associate Administrator.

4.6.4.5 Planetary Protection

The EOMP will be considered as complete when the rationale for selection of disposal of the spacecraft at extraterrestrial bodies has been documented. For objects remaining in Earth orbit, this section is not applicable.

4.6.5 Brief Summary of Mitigation Measures Used in NASA for this Area

Note: Sections a and b refer to Earth orbit only. Section c refers to all EOMPs.

a. For a program or project that elects to limit orbital lifetime using atmospheric drag and reentry, several options are available:

- Lower the initial perigee altitude for the disposal orbit;
- When deploying LEO spacecraft to altitudes above 700 km, utilize a lower altitude staging orbit, followed by spacecraft raising maneuvers, to accelerate the orbital decay of launch vehicle stages, in particular those with no re-start capability;
- Increase the area-to-mass ratio for the structure using drag augmentation but be aware of the issues regarding collision potential with resident space objects;
- For highly elliptical orbits, restrict the initial right ascension of ascending node of the orbit plane relative to the initial right ascension of the Sun so that the average perigee altitude is lowered naturally; and/or
- To increase the probability that the postmission disposal maneuver will be successful, consider incorporating redundancy into the postmission disposal system.

b. Additional options and more detailed descriptions can be found in Postmission Disposal of Upper Stages, JSC-27862 (December 1998). Many of these options are also applicable for the disposal of spacecraft.

c. The review of EOMPs during the program's operational life will help meet the goals and intent of this NASA-STD while keeping NASA management aware of the associated risks and EOM constraints.

4.7 Survival of Debris From the Postmission Disposal Earth Atmospheric Reentry Option

Orbital debris analyses assess the risks associated with the disposal of a space vehicle in Earth's Atmosphere.

4.7.1 Definition of the Reentry Debris Casualty Risk Technical Area

a. The use of atmospheric reentry to limit the orbital lifetime of space structures in conformance with Requirement 4.6-1 results in the transfer of an orbital environment risk to a potential human casualty risk.

b. The potential human casualty risk includes all prompt injuries due to the impact from falling debris as well as exposures to hazardous materials which include chemical, explosive, biological, and radiological materials. For the purposes of this NASA-Standard, a prompt injury is defined

as a medical condition received as a result of the falling debris which requires (or should have required) professional medical attention within 48 hours of the impact.

c. This section presents the requirement that defines the maximum human casualty risk permitted for either a controlled or uncontrolled reentry. An uncontrolled reentry is defined as the atmospheric reentry of a space structure in which the surviving debris impact cannot be guaranteed to avoid landmasses.

d. Requirement area 4.7 applies to all spacecraft and launch vehicles returning to the surface of the Earth from an altitude of greater than 100 km (~62 mi).

4.7.2 Requirements for the Area

NASA space programs and projects that use atmospheric reentry as a means of disposal for space structures need to limit the amount of debris that can survive reentry and pose a threat to people on the surface of the Earth. This area applies to full spacecraft as well as jettisoned components.

Requirement 4.7-1. Limit the risk of human casualty: The potential for human casualty is assumed for any object with an impacting kinetic energy in excess of 15 joules:

- a) For uncontrolled reentry, the risk of human casualty from surviving debris shall not exceed 0.0001 (1:10,000) ([Requirement 56626](#)).
- b) For controlled reentry, the selected trajectory shall ensure that no surviving debris impact with a kinetic energy greater than 15 joules is closer than 370 km from foreign landmasses, or is within 50 km from the continental U.S., territories of the U.S., and the permanent ice pack of Antarctica ([Requirement 56627](#)).
- c) For controlled reentries, the product of the probability of failure of the reentry burn (from Requirement 4.6-4.b) and the risk of human casualty assuming uncontrolled reentry shall not exceed 0.0001 (1:10,000) ([Requirement 56628](#)).

4.7.3 Rationale for the Area Requirements

a. In 1995 NASA established a policy of limiting the risk of world-wide human casualty from a single, uncontrolled reentering space structure to 1 in 10,000. In 1997 and again in 2001 this risk threshold was endorsed by its inclusion in the U.S. Government Orbital Debris Mitigation Standard Practices. The European Space Agency has also proposed, but not yet officially adopted, a reentry human casualty risk threshold of 1 in 10,000. The IADC is also examining this issue and is working to reach a consensus on an international requirement. To provide a reference for the reentry risk requirement, a 1999 study, sponsored by the NASA Office of Safety and Mission Assurance, compiled and compared U.S. Government-accepted human casualty risks in other transportation and non-transportation activities.

b. The principal factors in calculating the risk of human casualty from uncontrolled reentries include the number of debris expected to reach the surface of the Earth, the kinetic energy of each surviving debris, and the amount of the world population potentially at risk. The last factor is a function of both the orbital inclination of the space structure prior to reentry and the year in which the reentry occurs. To date, no casualties have been attributed to reentering artificial space structures.

- c. Extensive human casualty studies by the U.S. Government, including ones by the Department of Defense and the Department of Energy, have examined the probability of injury and/or death from falling debris for a variety of impacting kinetic energies to humans. A kinetic energy threshold criterion of 15 joules is widely accepted as the minimum level for potential injury to an unprotected person.
- d. The protection that a structure such as a single- or multi-story building or car provides an individual is dependent upon both the structure and the kinetic energy of the falling debris. Moreover, the typical degree of protection of a structure can be a function of the world region. It has been estimated that approximately 80% of the world's population is unprotected or in lightly-sheltered structures providing protection against falling debris with up to a few kilojoules (kJ) of kinetic energy. For the purpose of this NASA-STD, any debris with an impacting kinetic energy greater than 15 joules will be considered potentially hazardous for the majority of the world's population.
- e. Impacting debris, particularly large debris, can also bounce or fall over, effectively increasing the impact zone and, therefore, the risk to people. However, this risk increase is countered by the conservatism of the aforementioned sheltering assumption.
- f. Injuries to humans can occur from direct impact due to a falling object (see previous paragraphs) and exposure from the hazardous materials contained within a space object. While the calculation of the risk of prompt human injury from a hazardous material or a falling object is highly dependent on a number of a prior assumptions, it is the responsibility of the mission agency or agencies to protect the public by at least understanding if a realistic risk exists in this area.

4.7.4 Methods to Assess Compliance

- a. An important metric in the determination of risk from reentering debris is the debris casualty area. For a piece of debris that survives atmospheric reentry, the debris casualty area is the average debris cross-sectional area plus a factor for the cross-section of a standing individual. The total debris casualty area for a reentry event is the sum of the debris casualty areas for all debris pieces surviving atmospheric reentry. Equation 4.7-1 is used to calculate the total debris casualty area.

$$D_A = \sum_{i=1}^N (0.6 + \sqrt{A_i})^2 \quad (4.7-1)$$

where N is the number of objects that survive reentry and A_i is the area of surviving pieces.

- b. The average cross-sectional area of a standing individual, viewed from above, was taken to be 0.36 m^2 . The 0.6 term is then the square root of this area.
- c. The total human casualty expectation, E, is simply

$$E = D_A * P_D \quad (4.7-2)$$

where D_A is equal to the total casualty debris area and P_D is equal to the total average population density for the particular orbit.

d. Due to the complexity of satellite reentry physics and material responses, NASA programs and projects are required in paragraph 1.1.3 of this NASA-STD to employ either DAS or a higher fidelity model called ORSAT (Object Reentry Survival Analysis Tool) to determine compliance with Requirement 4.7-1. The reentry risk assessment portion of DAS contains a simplified model which does not require expert knowledge in satellite reentry analyses. Due to the need to make some simplifications, the model is designed to be somewhat conservative. The degree of conservatism is actually a function of the vehicle and the materials under evaluation.

e. If a properly performed DAS reentry risk assessment indicates that the risk is less than 0.0001, then the vehicle is compliant with Requirement 4.7-1. If the DAS result indicates a risk greater than 0.0001, the vehicle may still be compliant, but an ORSAT assessment will be needed to determine the actual risk. ORSAT is fully documented, maintained, and operated by trained personnel at JSC. In addition, ORSAT has been validated by comparisons with recovered satellite debris and compares well with the European SCARAB (Spacecraft Atmospheric Reentry and Aerothermal Breakup) model.

f. For a controlled reentry, the DAS or ORSAT risk assessment is multiplied by the failure probability of the controlled reentry (from Requirement 4.6-4) in order to determine whether the overall risk of human casualty is less than 0.0001 (1:10,000). For example, if a failure modes and effects analysis determines that there exists a 10% probability of failure of the controlled reentry maneuver, then the risk to human casualty must be less than 0.001 ($0.1 \times 0.001 = 0.0001$). If the probability of failure is 20%, the risk to human casualty must be less than 0.0005 ($0.2 \times 0.0005 = 0.0001$). For both controlled and uncontrolled reentry, the DAS or ORSAT evaluation must be performed to determine compliance with Requirement 4.7-1.

g. In the DAS or ORSAT risk assessment, the assumptions used to model the reentry are documented in the ODAR and include the explanation of which items are assemblies and their sub assemblies and which items resulting in $>15J$ impacts have been included.

h. For this technical area, it is suggested that illustrations and scenarios be used in the documentation of the analyses to assist in understanding the operations occurring.

i. The following considerations include, but are not limited to, items to be used for calculating the probability of a prompt human injury from a returning object containing hazardous materials:

- A prediction of the end state of the material (solid, liquid/powder, or gas) .
- For ionizing radioactive materials, only material quantities greater than 1 A2 (*Note: NPR 8715.3 Chapter 6 contains an explanation of A2 and how it is calculated and what approvals are required.*)
- For all explosive materials, if the heating or impact associated with terminal velocity could cause detonation or deflagration, the explosive force/hazard is calculated for the entire material.

- For biological materials which are not sterilized due to reentry, the risk due to release of the full material is assumed. Hazardous material risks are summed for all of the above assumptions and then added to the risk of human casualty due to impact.
- A de minimus value of 1:100,000 is used for determining risks due to hazardous materials. Only risks larger than the de minimus value will need explicit detailed calculations.

j. Reporting of hazardous materials and their associated risk is defined in Appendices A and B of this document for each ODA and EOM report. Reporting will be done in a table using the below format containing the columns listed in Appendices A and B.

- Column A: Chemical and commercial name of the material
- Column B: Very brief description of how material is a hazard to humans (aka: explosive, carcinogen, toxic, radioactive)
- Column C: Estimated material state (gas/liquid/solid/powder), amount/quantity/activity/pressure at launch
- Column D: Estimated state/quantity/pressure of the material onboard when the space structure reaches operational orbit (Columns D-G use the same format as in Column C).
- Column E: Estimated state/quantity/pressure of the material onboard at expected EOM.
- Column F: Estimated state/quantity/pressure of the material onboard at expected end of passivation.
- Column G: Estimated state/quantity/pressure of the material expected to survive reentry and strike the Earth's surface (Enter NONE if the space structure is not expected to reenter Earth).

4.7.5 Brief Summary of Mitigation Measures Used in NASA for this Area

If the amount of debris surviving reentry exceeds the requirement, then either the ground impact point is modified by a postmission disposal maneuver or measures are taken to reduce the amount of debris surviving reentry. Options to consider include:

- a. Performing a controlled reentry. Maneuver the structure at EOM to a reentry trajectory with an effective perigee altitude no higher than 50 km to control the location of the reentry and ground impact points (see Section 4.6).
- b. Using materials that are less likely to survive reentry, which is also known as 'design to demise.' Thermophysical and physical material properties of the space structure components, such as thermal conductivity, specific heat capacity, heat of fusion, melt temperature, heat of ablation, and density, have a significant effect on reentry survivability. In general, materials with high melting temperatures, such as titanium, beryllium, and stainless steel, are more likely to

survive than materials with low melting temperatures like aluminum. However, the configuration of the component is also very important.

- c. Causing a structure to break up immediately prior to reentry. If the components of a space structure can be exposed individually to the environment prior to structural breakup altitude at about 80 km, then additional heating will take place, facilitating component demise. In the extreme, a deliberate detonation of the space structure (see Section 4.4) before normal breakup would not only expose the components sooner, but also create a large number of smaller debris more susceptible to demise. Such a breakup would normally take place at an altitude below 120 km, which would prevent any debris from remaining in orbit.
- d. Maneuvering the structure at the end of the mission to a disposal orbit where reentry will not occur (see Section 4.6).
- e. Mitigation of hazardous materials is best done during the development of a space structure. The hazardous materials should be designed to either burn up during reentry, be sterilized during reentry, or be located within the structure such that the hazardous materials will not be released or detonate upon impact with the Earth's surface. For hazardous materials that will remain at EOM, it is best to expel any liquids or gaseous materials from the structure prior to reentry to lessen the ground hazard. If explosive materials will reach the ground after reentry, it may be best to explode the materials prior to reentry.

4.8 Additional Assessment Requirements for Tether Missions

Orbital debris analyses assess the potential hazard of tethered systems considering both an intact and severed system. Tethers are flexible long and narrow space structures with two of the dimensions much smaller than the third. The potential to damage operating spacecraft can be larger than would be expected solely from the tether mass and cross-sectional area. Requirement area 4.8 applies to all space structures using tethers in Earth or lunar orbits.

4.8.1 Definition of the Tether Technical Area

- a. Programs using tethers must take extra measures to control the potential for damaging other systems. To limit risk to other users of space, tethers left in orbit after completion of mission or tether fragments created when meteoroids or orbital debris sever the tether are considered debris.
- b. At the current time there is considerable uncertainty as to the final state of tethers or tether fragments that are not connected to end masses. If they remain extended, they may present a significant threat to operating spacecraft and a potential source of collision fragments from collisions with large debris.

4.8.2 Requirements for the Area

Requirement 4.8-1. Mitigate the collision hazards of space tethers in Earth or Lunar orbits:

Intact and remnants of severed tether systems in Earth and lunar orbit shall meet the requirements limiting the generation of orbital debris from on-orbit collisions (Requirements 4.5-1 and 4.5-2) and the requirements governing postmission disposal (Requirements 4.6-1 through 4.6-4) to the limits specified in those paragraphs ([Requirement 56652](#)).

4.8.3 Rationale for the Area Requirements

Due to their ability to sweep through large regions of space, tethers present an elevated risk to operating spacecraft. In addition, a tether collision with a large derelict spacecraft or orbital stage could create significant numbers of debris which, in turn, could pose risks to other resident space objects. Consequently, tethers or tether fragments left in orbit after completion of the mission require special consideration for the risks they may pose.

4.8.4 Methods to Assess Compliance

ODAR and EOMP assessments for tether systems are performed for both intact and severed conditions when performing trade-offs between alternative disposal strategies.

4.8.4.1 Limiting debris generated by tether collisions with large objects.

For known tether dimensions and mass, DAS will determine whether any tether has a probability of collision with large objects (10 cm or larger) less than 0.001.

4.8.4.2 Limiting debris generated by tether collisions with small objects

- a. Requirement 4.5-2 is only applicable if the tether or tether system is required for postmission disposal. DAS can determine compliance for simple tethers only.
- b. For missions in or passing through LEO, the probability, P , of a tether being hit by a small debris object during its mission lifetime can be approximated by the summation over debris/meteoroid diameter bins:

$$P = \sum f_i * A_{Ti} * T \quad (4.8-1)$$

where

- f_i = weighted cross-sectional area flux for the debris environment at the midpoint of the tether for debris/meteoroid objects of diameter i . Note this is the differential flux, whereas orbital debris and meteoroid fluxes are typically given as cumulative fluxes (flux of a given diameter or larger). Differential flux can be estimated by dividing up the flux into diameter bins. The flux in each diameter bin is the cumulative flux for the diameter in that bin minus the cumulative flux of the diameter in the next larger bin.
- A_{Ti} = collision cross-section for the tether in m^2 (= cross sectional area of tether), and is also dependent on particle diameter (see below)
- T = orbital lifetime in years

- c. The weighted cross-sectional area flux is derived by evaluating the amount of time the vehicle spends in different altitudes during its mission.
- d. The smallest diameter that can sever a particular tether is typically not a simple function but is analogous to ballistic equations for spacecraft surfaces that must be determined experimentally in a laboratory using hypervelocity gun tests. However, for the purposes of this requirement, the smallest particle (orbital debris or meteoroid) that can sever the tether is assumed to be 1/3 the

diameter of the tether. Therefore the summation in Equation 4.8-1 need only start at the minimum diameter particle to sever the tether.

e. The collision cross-section for a tether will be

$$A_{Ti} = D_{Ti} * L \quad (4.8-2)$$

where

- D_{Ti} = tether diameter in meters + diameter of orbital debris/meteoroid (for size diameter bin i) in meters
 L = length of tether in meters

f. For more complex tether designs using braided, multi-strand, or Hoyt tethers, the ODAR/EOMP documents the analysis (outside of DAS) to demonstrate compliance. This is done by determining the diameter of debris sufficient to sever the complex tether and using Equations 4.8-1 and 4.8-2 to evaluate the probability of collision with small debris sufficient to sever the tether.

4.8.4.3 Postmission Disposal of Tethers

Postmission disposal requirements include all tether fragments (Section 4.6). In the case of severing a deployed tether, the tether may be assumed to be cut in two equal halves. To calculate the orbit lifetime of one tether fragment, the average cross-sectional area will be the cross-sectional area of the tether, as defined above, plus the cross-sectional area of one end mass. The mass of each tether fragment will be one-half the mass of the tether plus the mass of the respective end mass. The ratio of mass to area calculated in this way will be used as the area-to-mass ratio for orbital lifetime calculations in DAS.

4.8.5 Brief Summary of Mitigation Measures Used by NASA for this Area

One or more of the following options may prove helpful to ensure compliance with Requirement 4.8-1:

- a. Detach the tether from the end masses at EOM to reduce the time the tether remains in orbit.
- b. Plan to retract the tether at EOM.
- c. Develop a tether design such that the tether will not be severed before mission completion, making the tether somewhat thicker, adding a protective cover to the tether, or constructing the tether as a ribbon or fiber matrix structure;.
- d. Perform the tether experiment at lower altitude.

APPENDIX A. Orbital Debris Assessment Reports (ODAR)

A.1 Format for ODARs

A.1.1 Delivery of the ODARs is governed by the requirements specified in NASA Procedural Requirements (NPR) 8715.6, paragraph 2.2 and NPR 7120.5, NASA Program Management. The nominal schedule is:

Note: See NPR 8715.3 paragraph 1.13 and NASA-STD 8709.20 for NASA SMA Requirement Relief process.

- Description of the “**Initial ODAR**” is contained in Appendix A, paragraph A.4.
- Delivery of “**PDR ODAR**” is at the mission Preliminary Design Review (PDR) for the spacecraft or equivalent program/project development milestone. The purpose of preparing the report early in the design and development process is to ensure that orbital debris issues are identified early when resolutions are least costly to implement. Any orbital debris mitigation compliance issues should be addressed and resolved no later than the Key Decision Point (KDP) B.
- Delivery of the “**CDR ODAR**” 45 days prior to the mission Critical Design Review (CDR) for the spacecraft or equivalent program/project development milestone. The purpose of the CDR ODAR is to update and clarify the issues and changes to the PDR Draft for any nonconformances which remain prior to beginning the launch approval process. Any orbital debris mitigation compliance issues should be addressed and resolved no later than the KDP C.
- A “**Final ODAR**” submitted 30 days prior to the Safety and Mission Success Review (SMSR) as a part of the launch approval process.

A.1.2 The PDR ODAR, CDR ODAR and Final ODAR shall be delivered in both electronic and paper copies to the OSMA (Requirement).

A.1.3 In accordance with NPR 8715.6, paragraph 2.2, each ODAR delivery is reviewed by the OSMA with technical assistance from the NASA Orbital Debris Program Office (ODPO) with final approval and all associated risks are accepted by the Associate Administrator of the Mission Directorate sponsoring the mission.

Note: Programs are encouraged to use existing program documentation for mission and spacecraft descriptions.

A.1.4 When a spacecraft is jointly developed/built/operated by multiple organizations outside of the United States or is restricted by national defense or corporate proprietary restrictions, and the ODAR contains material restricted by export controls, such as international traffic of arms regulations (ITAR), then a full version of the ODAR material shall be prepared and delivered to the NASA ODPO in addition to the material being provided to organizations outside of NASA as permitted by ITAR and other data restrictions (Requirement)

A.1.5 Each ODAR shall follow the format below and include the content indicated at a minimum (Requirement).

Note: To ease preparing and using the ODAR, orbital debris mitigation requirements for the spacecraft and launch vehicle are addressed in separate sections (Sections 2 through 8 and Sections 9 through 14, respectively).

Note: The text associated with each ‘item’ listed below is intended as guidance in developing the content in the ODARs and is not intended to imply that the item text is required to be repeated verbatim in the ODARs.

ODAR Cover and Front Matter

- Cover showing the document version and date of delivery
- Inside cover showing the signatures on that report. This signatures on the PDR ODAR and CDR ODAR include (as a minimum):
 - Submitted by: Document preparer(s), program management
 - Concurrence by: NASA HQ program/project management, and the NASA HQ Office of Safety and Mission Assurance Orbital Debris Manager
 - Approval and Risk accepted by: sponsoring Mission Directorate Associate Administrator.
 - For the Final ODAR, in addition to the above signature, include a concurrence by the NASA Chief, Safety and Mission Assurance.
- Self assessment of the ODAR using the format in Appendix A.2 of this NASA-STD
- Statement of any restrictions on the data in the ODAR such as proprietary, ITAR, or export controls. If the document does not contain any restrictions, then a statement to that effect must be included. If the document does contain restricted information, the restricted information must be summarized and marked clearly on the page(s) where it occurs and on the cover.
- Document history page showing each version of the report. Reviews of the previous versions by the OSMA must be included in this section.
- DAS version used, or if software and models other than DAS are used, a description of the software/model.

ODAR Section 1: Program Management and Mission Overview

- Identification of the Headquarters Mission Directorate sponsoring the mission and the Program Executive
- Identification of the responsible program/project manager and senior scientific and management personnel
- Identification of any foreign government or space agency participation in the mission and a summary of NASA’s responsibility under the governing agreement(s)
- Clear schedule of mission design and development milestones from NASA mission selection through proposed launch date, including spacecraft PDR and CDR (or equivalent) dates
- Brief description of the mission
- Identification of the anticipated launch vehicle and launch site

- Identification of the proposed launch date and mission duration
- Description of the launch and deployment profile, including all parking, transfer, and operational orbits with apogee, perigee, and inclination
- Reason for selection of operational orbit(s) (such as ground track, SSO, GEO sync, instrument resolution, co-locate with other spacecraft, ...)
- Identification of any interaction or potential physical interference with other operational spacecraft (*Note: This does not include potential for RF interaction unless it affects the risk of generating orbital debris.*)

ODAR Section 2: Spacecraft Description

- Physical description of the spacecraft, including spacecraft bus, payload instrumentation, and all appendages, such as solar arrays, antennas, and instrument or attitude control booms
- Detailed illustration of the entire spacecraft in the mission operation configuration with clear overall dimensional markings and marked internal component locations
- Total spacecraft mass at launch, including all propellants and fluids
- Dry mass of spacecraft at launch, excluding solid rocket motor propellants
- Description of all propulsion systems (cold gas, mono-propellant, bi-propellant, electric, nuclear)
- Identification, including mass and pressure, of all fluids (liquids and gases) planned to be on board and a description of the fluid loading plan or strategies, excluding fluids in sealed heat pipes. Description of all fluid systems, including size, type, and qualifications of fluid containers such as propellant and pressurization tanks, including pressurized batteries
- Description of all active and/or passive attitude control systems with an indication of the normal attitude of the spacecraft with respect to the velocity vector
- Description of any range safety or other pyrotechnic devices
- Description of the electrical generation and storage system
- Identification of any other sources of stored energy not noted above
- Identification of any radioactive materials on board or make a positive statement that there are no radioactive materials onboard

ODAR Section 3: Assessment of Spacecraft Debris Released during Normal Operations

- Identification of any object (>1 mm) expected to be released from the spacecraft any time after launch, including object dimensions, mass, and material
- Rationale/necessity for release of each object
- Time of release of each object, relative to launch time
- Release velocity of each object with respect to spacecraft
- Expected orbital parameters (apogee, perigee, and inclination) of each object after release
- Calculated orbital lifetime of each object, including time spent in Low Earth Orbit (LEO)
- Assessment of spacecraft compliance with Requirements 4.3-1 and 4.3-2

ODAR Section 4: Assessment of Spacecraft Intentional Breakups and Potential for Explosions.

- Identification of all potential causes of spacecraft breakup during deployment and mission operations
- Summary of failure modes and effects analyses of all credible failure modes which may lead to an accidental explosion
- Detailed plan for any designed spacecraft breakup, including explosions and intentional collisions
- List of components which are passivated at EOM. List includes method of passivation and amount which cannot be passivated.
- Rationale for all items which are required to be passivated, but can not be due to their design.
- Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4

ODAR Section 5: Assessment of Spacecraft Potential for On-Orbit Collisions

- Calculation of spacecraft probability of collision with space objects larger than 10 cm in diameter during the orbital lifetime of the spacecraftCalculation of spacecraft probability of collision with space objects, including orbital debris and meteoroids, of sufficient size to prevent postmission disposal
- Assessment of spacecraft compliance with Requirements 4.5-1 and 4.5-2

ODAR Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

- Description of spacecraft disposal option selected
- Identification of all systems or components required to accomplish any postmission disposal operation, including passivation and maneuvering
- Plan for any spacecraft maneuvers required to accomplish postmission disposal
- Calculation of area-to-mass ratio after postmission disposal, if the controlled reentry option is not selected
- If appropriate, preliminary plan for spacecraft controlled reentry
- Assessment of spacecraft compliance with Requirements 4.6-1 through 4.6-5

ODAR Section 7: Assessment of Spacecraft Reentry Hazards

- Detailed description of spacecraft components by size, mass, material, shape, and original location on the space vehicle, if the atmospheric reentry option is selected
- Summary of objects expected to survive an uncontrolled reentry, using NASA Debris Assessment Software (DAS), NASA Object Reentry Survival Analysis Tool (ORSAT), or comparable software
- Calculation of probability of human casualty for the expected year of uncontrolled reentry and the spacecraft orbital inclination
- Assessment of spacecraft compliance with Requirement 4.7-1

ODAR Section 7A: Assessment of Spacecraft Hazardous Materials

- Summary of the hazardous materials contained on the spacecraft using all columns and the format in paragraph 4.7.5.

ODAR Section 8: Assessment for Tether Missions

- Type of tether; e.g., momentum or electrodynamics
- Description of tether system, including (1) tether length, diameter, materials, and design (single strand, ribbon, multi-strand mesh), at a minimum and (2) end-mass size and mass
- Determination of minimum size of object that will cause the tether to be severed
- Tether mission plan, including duration and postmission disposal
- Probability of tether colliding with large space objects
- Probability of tether being severed during mission or after postmission disposal
- Maximum orbital lifetime of a severed tether fragment
- Assessment of compliance with Requirement 4.8-1

ODAR Section 9: Launch Vehicle Description

- Identification of launch vehicle to be used
- Identification of any non-basic upper stages to be used
- Identification of any launch vehicle stage which will be inserted into Earth orbit and left there
- Dry mass of each orbital stage after spacecraft deployment
- Detailed illustration of each orbital stage with clear dimensional markings and marked internal component locations

ODAR Section 10: Assessment of Launch Vehicle Debris Released During Normal Operations

- Identification of any object greater than 1 mm which will be released into Earth orbit from any stage, including, but not limited to, dual payload attachment fittings and stage separation devices
- Rationale/necessity for release of each object
- Time of release of each object, relative to launch time
- Release velocity of each object with respect to orbital stage
- Expected orbital parameters (apogee, perigee, and inclination) of each object after release
- Calculated orbital lifetime of each object, including time spent in Low Earth Orbit (LEO)
- Assessment of launch vehicle compliance with Requirements 4.3-1 and 4.3-2

ODAR Section 11: Assessment of Launch Vehicle Potential for Explosions and Intentional Breakups

- For Section 11, each orbital launch vehicle stage/piece is addressed separately (*Note: There may be multiple Chapter 11's*)
- Identification of all potential causes of launch vehicle in orbit breakup during all operations

- Summary of failure modes and effects analyses of all credible failure modes which may lead to an orbital stage accidental explosion
- Detailed plan for any designed orbital stage breakup, including explosions and intentional collisions
- Detailed plan, under normal EOM conditions and deployment malfunction scenario, for passivating (depleting all energy sources) each orbital stage, including the burning or release of all propellants and fluids
- Assessment of launch vehicle compliance with Requirements 4.4-1 through 4.4-4

ODAR Section 12: Assessment of Launch Vehicle Potential for On-orbit Collisions

- Calculation of each orbital stage probability of collision with space objects larger than 10 cm in diameter during the orbital lifetime of the stage
- Assessment of launch vehicle compliance with Requirement 4.5-1

ODAR Section 13: Assessment of Launch Vehicle Postmission Disposal Plans and Procedures

- Description of orbital stage disposal option selected
- Plan for any orbital stage maneuvers required to accomplish disposal after end of orbital stage mission
- Calculation of area-to-mass ratio after completion of all orbital stage operations, including disposal maneuvers, if the controlled reentry option is not selected
- Procedure for executing orbital stage disposal plan, including timeline from final shut-down of each orbital stage to completion of passivation and disposal operations
- Demonstration of reliability of orbital stage disposal operations
- Assessment of launch vehicle compliance with Requirements 4.6-1 through 4.6-4
- If appropriate, preliminary plan for launch vehicle controlled reentry

ODAR Section 14: Assessment of Launch Vehicle Reentry Hazards

Note: If an ORSAT reentry hazard assessment has already been performed for an orbital stage, simply refer to that report and make any necessary adjustments for orbital inclination and year of reentry.

- Detailed description of launch vehicle components by size, mass, material, and shape, if the atmospheric reentry option is selected, also indicate the location of that component within the vehicle.
- Summary of objects expected to survive an uncontrolled reentry, using NASA DAS, NASA ORSAT, or comparable software. If the version of the tool used is different from that cited in the cover section, then list it here
- Calculation of probability of human casualty for the expected year of uncontrolled reentry and the orbital stage inclination
- Assessment of launch vehicle compliance with Requirement 4.7-1

ODAR Section 14A: Assessment of Launch Vehicle Hazardous Materials

- Summary of the hazardous materials contained on the launch vehicle using all columns and the format in paragraph 4.7.5.

A.2 Review of ODARs

In accordance with NPR 8715.6, Section 2.2, each delivered ODAR will be reviewed by the OSMA and by the Space Operations Mission Directorate with technical assistance from the NASA ODPO. After the OSMA review, the check sheet in Figure A.2-1 will be returned to the Headquarters Sponsoring Mission Directorate Program Executive for distribution back to the program. OSMA will also provide a copy to the orbital debris lead at the Center supporting the program for assisting with corrective actions.

Orbital Debris Assessment Report Evaluation: _____ Mission

(based upon ODAR _____ version, dated _____, 201_)

Reqm't #	Launch Vehicle				Spacecraft			Comments
	Compliant	Not Compliant	Incomplete	Standard Non Compliant	Compliant or N/A	Not Compliant	Incomplete	
4.3-1.a	☐	☐	☐	☐	☐	☐	☐	
4.3-1.b	☐	☐	☐	☐	☐	☐	☐	
4.3-2	☐	☐	☐	☐	☐	☐	☐	
4.4-1	☐	☐	☐	☐	☐	☐	☐	
4.4-2	☐	☐	☐	☐	☐	☐	☐	
4.4-3	☐	☐	☐	☐	☐	☐	☐	
4.4-4	☐	☐	☐	☐	☐	☐	☐	
4.5-1	☐	☐	☐	☐	☐	☐	☐	
4.5-2	☐	☐	☐	☐	☐	☐	☐	
4.6-1(a)	☐	☐	☐	☐	☐	☐	☐	
4.6-1(b)	☐	☐	☐	☐	☐	☐	☐	
4.6-1(c)	☐	☐	☐	☐	☐	☐	☐	

Reqm't #	Launch Vehicle				Spacecraft			Comments
	Compliant	Not Compliant	Incomplete	Standard Non Compliant	Compliant or N/A	Not Compliant	Incomplete	
4.6-2	☐	☐	☐	☐	☐	☐	☐	
4.6-3	☐	☐	☐	☐	☐	☐	☐	
4.6-4	☐	☐	☐	☐	☐	☐	☐	
4.7-1	☐	☐	☐	☐	☐	☐	☐	
4.8-1	[Hatched Pattern]				☐	☐	☐	

Additional Comments:

Reviewed by: _____ on: ____/____/____

Figure A.2-1: ODAR Review Check sheet

A.3 Abbreviated ODARs

A.3.1 For portions of spacecraft and missions where an abbreviated ODAR is required per NPR 8715.6, paragraph 2.1.1, Table A.3-1 of this NASA-STD lists the sections of the ODAR defined in Section A.1 that shall be included as a minimum (Requirement).

A.3.2 From NPR 8715.6, paragraph 2.1.1 and 2.2, Abbreviated ODARs:

- Address and analyze only the NASA portion of the program.
- Are submitted by the NASA Project Manager, reviewed by the NASA OSMA and the ODPO and approved/risk accepted by the Mission Directorate Associate Administrator.
- Are delivered as a part of the hardware delivery turnover.

A.3.3 NPR 8715.6, paragraphs 2.1.3 and 2.1.4, provide special instructions for the need to generate two versions of the Abbreviated-ODAR.

A.3.4 The Abbreviated ODAR(s) shall be delivered in both electronic and paper copies to the OSMA (Requirement).

Table A.3-1: Mandatory Sections in an Abbreviated ODAR.

ODAR Section Name	Mandatory Portion of ODAR Section as defined in Appendix A, paragraph A.1.6, to include
ODAR Cover, Signatures, and Front Matter	All
<u>ODAR Section 1</u> : Program Management and Mission Overview	Program demographics and mission of items being delivered
<u>ODAR Section 2</u> : Spacecraft Description	Description of items being delivered
<u>ODAR Section 3</u> : Assessment of Spacecraft Debris Released during Normal Operations	Analysis of any material planned for release during normal operations

ODAR Section Name	Mandatory Portion of ODAR Section as defined in Appendix A, paragraph A.1.6, to include
<u>ODAR Section 4</u> : Assessment of Spacecraft Potential for Explosions and Intentional Breakups	Summary of failure modes and effects analyses of all credible failure modes which may lead to an accidental explosion of the spacecraft from the delivered hardware. List of components which are planned to be passivated at EOM, including the method of passivation and amount which cannot be passivated.
<u>ODAR Section 5</u> : Assessment of Spacecraft Potential for On-Orbit Collisions	Not required
<u>ODAR Section 6</u> : Assessment of Spacecraft Postmission Disposal Plans and Procedures	Not required
<u>ODAR Section 7</u> : Assessment of Spacecraft Reentry Hazards	Summary of objects expected to survive an uncontrolled reentry, using NASA Debris Assessment Software (DAS), NASA Object Reentry Survival Analysis Tool (ORSAT), or comparable software
<u>ODAR Section 7A</u> : Assessment of Spacecraft Hazardous Materials	All
<u>ODAR Section 8</u> : Assessment for Tether Missions	If delivered hardware includes a tether, include all, otherwise not required.
ODAR Sections 9 through 14: Launch Vehicle	If delivered hardware is the launch vehicle, include all, otherwise not required.

A.4 Initial ODAR

A.4.1 The **Initial ODAR** (which may also referred to as the Pre-Acquisition ODAR) shall analyze only the NASA portion of the program and any portions of the program which are driven/defined by a NASA acquisition decision (Requirement).

Note: See NPD 1000.5, NPR 7120.5, and NPR 8715.6 for specific reporting requirements.

Note: See Appendix A, Paragraph A.1 for requirements for preparation and delivery of Initial ODARs.

A.4.2 In accordance with NPR 8715.6. paragraph 2.2, the **Initial ODAR**:

- Is submitted/signed by the NASA Project Manager (or Mission Directorate Point of Contact if Project Manager has not been assigned) and submitted to the OSMA a minimum of 30 calendar days prior to the Acquisition Strategy Meeting (ASM).
- Is reviewed by the NASA Orbital Debris Program Office
- Is technically reviewed and receive concurrence by the NASA Chief Engineer and the Chief/Safety and Mission Assurance prior to submission to Mission Directorate Associate Administrator approval and acceptance of risk.
- Comments are provided by the OSMA to the Mission Directorate prior to the ASM.

A.4.3 The **Initial ODAR** shall be delivered to OSMA in both electronic and hard copy format (Requirement).

A.4.5 Any potential nonconformances identified on the **Initial ODAR** shall require either a formal request for a requirement deviation to requirements in this document (per NPR 8715.3 paragraph 1.13) or be corrected prior to the KDP A (as defined in NPR 7120.5) (Requirement).

A.4.6 The **Initial ODAR** shall follow either the format specified in paragraph A.4.6.1 or A.4.6.2 for development of a complete spacecraft or an instrument and/or component set, respectively (Requirement):

A.4.6.1: Full Spacecraft Development **Initial ODAR** format:

Initial ODAR Cover and Front Matter

- Cover showing the mission name, document version, and date of delivery
- Inside cover showing the signatures (as a minimum):
 - o Submitted by: Document preparer(s), program management
 - o Concurrence by: NASA HQ program/project management and the NASA HQ Office of Safety and Mission Assurance Orbital Debris Manager
 - o Approval and Risk Accepted by: sponsoring Mission Directorate Associate Administrator.
- Statement of any restrictions on the data in the Initial ODAR such as proprietary, ITAR, or export controls. If the document does not contain any restrictions, then a statement to that effect must be included. If the document does contain restricted information, the restricted information must be summarized and marked clearly on the page(s) where it occurs and on the cover.

Initial ODAR Section 1: Mission Overview

- Brief description of the mission,
- Identification potential launch vehicle, and launch site
- Brief description of the spacecraft, including spacecraft bus, payload instrumentation, and all appendages, such as solar arrays, antennas, and instrument or attitude control booms (an illustration is desired) and estimated spacecraft mass/size
- Description of all propulsion systems (cold gas, monopropellant, bipropellant, electric, nuclear)

- Identification of any radioactive materials or other non-propulsion system hazardous materials on board
- Description of operational orbital maintenance requirements (i.e., Sun-sync, ground track, altitude, formation flying)

Initial ODAR Section 2: Orbital Debris Limitation Summary

Note: The following 10 questions should be answered to convey the intended plan for the spacecraft and launch vehicle being presented at the ASM. Further analyses is not needed at this time. Short answers are acceptable/encouraged.

Note: In the parentheses after the paragraph is the answer which conforms to the requirements in this NASA-STD and the paragraph where further information can be found. This reference will be useful to the Program if deviations will be needed.

1. Can spacecraft propellant and pressurant tanks be emptied at end of mission? *(Should be vented, used, and/or emptied – paragraph 4.4 & 4.4.4.1.2)*
2. Can the spacecraft battery be disconnected from the charging circuit at end of mission? *(Yes – paragraph 4.4 & 4.4.4.1.2)*
3. If the answer to either of questions 1 and/or 2 is negative, what alternatives are available (bus modification or different bus) and at what additional, if any, cost?
4. Have all mission-related debris generation been eliminated to the greatest extent possible? *(Yes – paragraph 4.2, et al)*
5. For spacecraft operating in low Earth orbit (less than 2000 km), will the spacecraft reenter the atmosphere within 25 years after end of mission (and no more than 30 years after launch) or will the spacecraft be moved to a disposal orbit above 2000 km? *(Yes if applicable – paragraph 4.6 & 4.6.2.1)*
6. For spacecraft operating in GEO, will the spacecraft be moved to a compliant disposal orbit, i.e., one which will remain at least 200 km (~125 mi) above/below GEO for at least 100 years? *(Yes if applicable – paragraph 4.6 & 4.6.2.2)*
7. Will all launch vehicle orbital stages and mission-related debris be left in low Earth orbits with orbital lifetimes of less than 25 years or left in compliant disposal orbits above 2,000 km (~1,240 mi)? *(Yes if applicable – paragraph 4.6 & 4.6.2.1)*
8. If an uncontrolled atmospheric reentry is anticipated after EOM, does the spacecraft bus or the payload contain any objects which might survive reentry, e.g., tanks, structural components, or other items made of high melting temperature materials such as titanium, beryllium, or stainless steel? *(If applicable, no objects should survive which will strike the Earth with greater than 15 Joules of energy, list all expected objects over 1 kg– paragraph 4.7 & 4.7.2)*

9. If a disposal maneuver is planned for a mission not utilizing a controlled reentry, will the spacecraft propulsion system have a designed reliability of at least 0.9 at EOM? (*Yes if applicable – paragraph 4.6 & 4.6.2.4*)
10. Does the spacecraft have any critical components, other than sensors and solar cells, which are exposed to the environment without MMOD protection? (*No*)

A.4.6.2 Spacecraft Instrument or Component Development **Initial ODAR** Format:

Initial ODAR Cover and Front Matter

- Cover showing the mission name, document version, and date of delivery
- Inside cover showing the signatures (as a minimum):
 - o Submitted by: Document preparer(s), program management
 - o Concurrence by: NASA HQ program/project management and the NASA HQ Office of Safety and Mission Assurance Orbital Debris Manager
 - o Approval and Risk Accepted by: sponsoring Program Manager.
- Statement of any restrictions on the data in the Initial ODAR such as proprietary, ITAR, or export controls. If the document does not contain any restrictions, then a statement to that effect must be included. If the document does contain restricted information, the restricted information must be summarized and marked clearly on the page(s) where it occurs and on the cover.

Initial ODAR Section 1: Mission Overview

- Brief description of the instrument(s) and component(s) including a description of all propellants, pressurized tanks, any radioactive materials, or other non-propulsion system hazardous materials on board

Initial ODAR Section 2: Orbital Debris Limitation Summary

Note: The following 5 questions should be answered to convey the intended plan for the spacecraft and launch vehicle being presented at the ASM. Further analyses is not needed at this time. Short answers are acceptable/encouraged.

Note: In the parentheses after the paragraph is the answer which conforms to the requirements in this NASA-STD and the paragraph where further information can be found. This reference will be useful to the Program if deviations will be needed.

1. Can instrument/component propellant and pressurant tanks be emptied at end of mission? (N/A or *should be vented, used, and/or emptied – paragraph 4.4 & 4.4.4.1.2*)
2. Can the instrument/component battery be disconnected from the charging circuit at end of mission? (N/A or *Yes – paragraph 4.4 & 4.4.4.1.2*)
3. Have all mission-related debris generation been eliminated to the greatest extent possible? (*Yes – paragraph 4.2, et al.*)
4. If an uncontrolled atmospheric reentry is anticipated after EOM, are there any objects in the instrument/component which might survive reentry; e.g., tanks, structural

components, or other items made of high melting temperature materials such as titanium, beryllium, or stainless steel? *(If applicable, no objects should survive which will strike the Earth with greater than 15 Joules of energy, list all expected objects over 1 kg—paragraph 4.7 & 4.7.2)*

5. Does the instrument/component have any critical components, other than sensors and solar cells, which are exposed to the environment without MMOD protection? *(No)*

APPENDIX B: EOMPs

The EOMP is a living document that grows with the program as it operates. Please note that it is recognized that the level of detail in the EOMP prior to launch may be limited and it is intended to only be complete as the EOM approaches.

B.1 Format for EOMPs

B.1.1 Delivery of the EOMPs is governed by the requirements specified in NASA Procedural Requirements (NPR) 8715.6, paragraph 2.2 and NPR 7120.5, NASA Program Management. The nominal schedule is:

Note: See NPR 8715.3 paragraph 1.13 and NASA-STD 8709.20 for NASA SMA Requirement Relief process.

- Delivery of the “**Prelaunch EOMP**” 30 days prior to the Safety and Mission Success Review (SMSR). Formal acceptance of the risk associated with the nonconformances remaining in the EOMP is included as a part of the prelaunch risk acceptance.
- Delivery of updates to the EOMP (titled: “[*date*] **Update to the EOMP**”) is made at the major program operational milestones identified in the EOMP.
- The “**Pre-Decommissioning EOMP**” is delivered at 30 days prior to the expected Decommissioning Review. The approved version is included in the Pre-Decommissioning Review data package.

NOTE: This is approximately the same time that the notice of intent to shutdown the spacecraft is delivered to the NASA Associate Administrator per NPD 8010.3A, Notification of Intent to Decommission or Terminate Operating Space Systems and Terminate Missions. It is desired that the EOMP accompany this letter.

- The “**Pre-Disposal EOMP**” is delivered at 30 days prior to the Disposal readiness Review. The approved version is included in the Disposal Readiness Review data package.

B.1.2 All EOMPs shall be delivered in both electronic and paper copies to the OSMA (Requirement).

B.1.3 In accordance with NPR 8715.6, paragraph 2.2, each EOMP is reviewed by the OSMA with technical assistance from the NASA Orbital Debris Program Office (ODPO) with final approval and all associated risks are accepted by the Associate Administrator of the Mission Directorate sponsoring the mission.

Note: Programs are encouraged to use existing program documentation for mission and spacecraft descriptions.

B.1.4 When a spacecraft is jointly developed/built/operated by multiple organizations outside of the United States or is restricted by national defense or corporate proprietary restrictions, and the ODAR or the EOMP contains material restricted by export controls, such as international traffic of arms regulations (ITAR), then a full version of the ODAR and EOMP material shall be prepared and delivered to the NASA ODPO in addition to the material being provided to organizations outside of NASA as permitted by ITAR and other data restrictions (Requirement).

B.1.5 Each EOMP shall follow the format below and include the content indicated at a minimum (Requirement).

Note: Programs are encouraged to use existing program documentation and the ODAR for mission and spacecraft descriptions and identification of the EOM decommissioning issues. The below listing identifies the data needed prior to launch and additional data needed during EOMP updates.

EOMP Cover and Front Matter

(all data is needed prior to launch)

- Cover showing the document version and date of delivery.
- Inside cover showing the signatures. This includes as a minimum: Document preparer(s), program management, NASA Headquarters program/project management, and the NASA OSMA Orbital Debris Program Executive.
- Inside cover showing the signatures on that report. This signatures on the PDR ODAR and CDR ODAR include (as a minimum):
 - Submitted by: Document preparer(s), program management
 - Concurrence by: NASA HQ program/project management, and the NASA HQ Office of Safety and Mission Assurance Orbital Debris Manager
 - Approval and Risk accepted by: sponsoring Mission Directorate Associate Administrator.
 - For the Initial EOMP, Pre-Decommissioning EOMP, and Pre-Disposal EOMPs, in addition to the above signature, include a concurrence by the NASA Chief, Safety and Mission Assurance.
- Self assessment of the EOMP using the format in Appendix B.2 of this NASA-STD for either the Prelaunch EOMPs (Figure B.2-1) or the Update, Pre-Decommissioning, or Pre-Disposal EOMPs (Figure B.2-2).
- Statement of any restrictions on the data in the EOMP such as proprietary, ITAR, or export controls. If the document does not contain any restrictions, then a statement to that effect must be included. If the document does contain restricted information, the restricted information must be summarized and marked clearly on the page(s) where it occurs and on the cover.
- Document history page showing each version of the report. Reviews of the previous versions by the OSMA is included in this page.
- DAS version used, or if software and models other than DAS are used, a description of the software/model.

EOMP Section 1: Program Management and Mission Overview

(data needed prior to launch)

- Identification of the Mission Directorate sponsoring the mission and the Program Executive
- Identification of the responsible program/project manager and senior scientific and management personnel

- Identification of any foreign government or space agency participation in any phase of the mission
- Clear schedule of mission operational milestones from launch through EOM
- Brief description of the mission (single paragraph)
- Description of operational orbits with apogee, perigee, and inclination

(data added during flight)

- Chronology of management reviews of the EOMP to include changes in spacecraft operability which may affect the ability to passivate and dispose per the plan in Section 6 of the EOMP

EOMP Section 2: Spacecraft Description

The ODAR Section 2 contains a full description of the spacecraft. Since the ODAR remains a reference, it does not need to be repeated here.

(all data added during flight)

- Table of the following onboard the spacecraft at time of issue of EOMP version, expected at commencement of passivation, and expected at completion of passivation.
 - o Fluids
 - o Pyrotechnic devices
 - o Electrical generation and storage system
 - o Identification of any other sources of stored energy not noted above
 - o Any radioactive materials
- List of changes in the propulsion systems and energy systems which have occurred since launch. Include a detailed illustration of the entire spacecraft in the EOM configuration with clear dimensional markings and marked internal component locations
- Total mass of post-passivation spacecraft, including all propellants and fluids
- Status of the major systems on board the spacecraft, including any changes in redundancy

EOMP Section 3: Assessment of Spacecraft Debris Released During and After Passivation

(data needed prior to launch)

- Identification of any solid object (>1 mm) expected to be released during passivation

(data added during flight)

- Identification of all objects (>1 mm) expected to be released (including fluids)
- Rationale/necessity for release of each object
- Time of release of each object, relative to passivation
- Release velocity of each object with respect to spacecraft
- Expected orbital parameters (apogee, perigee, and inclination) of each object after release
- Calculated orbital lifetime of each object, including time spent in Low Earth Orbit (LEO)
- Assessment of spacecraft compliance with Requirements 4.3-1 and 4.3-2

EOMP Section 4: Assessment of Spacecraft Potential for Explosions and Intentional Breakups

(data needed prior to launch)

- Identification of all potential causes of spacecraft breakup during passivation and after passivation
- Assessment of spacecraft compliance with Requirements 4.4-2 and 4.4-3

(data added during flight)

- Summary of remaining failure modes and effects analyses of all credible failure modes which may lead to an accidental explosion during passivation and after passivation.
- Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4

EOMP Section 5: Assessment of Spacecraft Potential for On-orbit Collisions

(data needed prior to launch)

- Evaluation of the vulnerability of systems required for postmission disposal to impacts by small space objects
- Assessment of EOM spacecraft compliance with Requirement 4.5-2

(data added during flight)

- Calculation of spacecraft probability of collision with space objects larger than 10 cm in diameter during the orbital lifetime of the spacecraft after passivation
- Assessment of EOM spacecraft compliance with Requirements 4.5-1 and 4.5-2

EOMP Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

(data needed prior to launch)

- Identification of all systems or components required to accomplish any postmission disposal operation, including passivation and maneuvering
- Description of spacecraft disposal option selected
- Demonstration of reliability of postmission disposal operations
- Calculation of area-to-mass ratio after postmission disposal, if the controlled reentry option is not selected
- Assessment of spacecraft compliance with Requirements 4.6-1 through 4.6-5

(data added during flight)

- Plan for any spacecraft maneuvers required to accomplish postmission disposal
- Procedure for executing postmission disposal plan
- Detailed plan for passivating (depleting all energy sources) the spacecraft, including the burning or release of all propellants and fluids, , the disabling of charging circuits, and the de-energizing of rotational energy sources per requirement 4.4-2
- Assessment of spacecraft compliance with Requirements 4.6-1 through 4.6-5

EOMP Section 7: Assessment of Spacecraft Reentry Hazards

(all data added during flight)

- Detailed description of spacecraft components by size, mass, material, and shape, if the atmospheric reentry option is selected, includes assumptions for type of breakup
- Summary of objects expected to survive an uncontrolled reentry, using NASA Debris Assessment Software (DAS), NASA Object Reentry Survival Analysis Tool (ORSAT), or comparable software
- Calculation of probability of human casualty for uncontrolled reentry and the spacecraft orbital inclination, based on the expected date of reentry
- If appropriate, preliminary plan for spacecraft controlled reentry
- Assessment of spacecraft compliance with Requirement 4.7-1

EOMP Section 7A: Assessment of Spacecraft Hazardous Materials

- Summary of the hazardous materials contained on the spacecraft using the format in paragraph 4.7.4 and containing:
 - o Prelaunch EOMPs: Columns A-G
 - o EOMP updates during operations: Columns A, B, E-G and Column D for current inventory of materials
 - o Final EOMP: Columns A, B, E-G.

EOMP Section 8: Assessment for Tether Missions

(all data added during flight)

- Description of tether system, including (1) tether length, diameter, materials, and design (single strand, ribbon, multi-strand mesh) at a minimum and (2) end-mass size and mass remaining at EOM
- Assessment of compliance with Requirement 4.8-1

EOMP Appendices: Additional EOM Data

- The Program may add additional appendices for documenting the final disposition of other program elements if it is felt that the EOMP is the most advantageous place for documenting them.

EOMP Addendum: Final ODAR

- For the Final EOMP, a copy of the Final ODAR is included for reference.

B.2 Review of EOMPs

Each EOMP delivered will be reviewed by the OSMA with technical assistance from the NASA ODPO. After the OSMA review, the check sheet in Figure B.2-1 (prelaunch EOMP) or Figure B.2-2 (Final EOMP) will be returned to the Headquarters Sponsoring Mission Directorate Program Executive for distribution back to the program. OSMA will also provide a copy to the Center SMA organization supporting the program for assisting with corrective actions.

Prelaunch EOMP Evaluation: _____ Mission

(based upon EOMP _____ version, dated _____, 201_)

Reqm't #	Compliant or N/A	Not Compliant	Incomplete	Comments
4.3-1.a				
4.3-1.b				
4.3-2				
4.4-1				
4.4-2	☐	☐	☐	
4.4-3	☐	☐	☐	
4.4-4				
4.5-1				
4.5-2	☐	☐	☐	
4.6-1(a)	☐	☐	☐	
4.6-1(b)	☐	☐	☐	
4.6-1(c)	☐	☐	☐	
4.6-2	☐	☐	☐	
4.6-3	☐	☐	☐	
4.6-4	☐	☐	☐	
4.7-1				
4.8-1				

Additional Comments:

Reviewed by: _____ on: ____/____/____

Figure B.2-1: Prelaunch EOMP Review Check Sheet

In-Flight, Pre-Decommissioning, and Pre-Disposal EOMP Evaluation: _____ Mission

(based upon EOMP _____ version, dated _____, 201_)

Reqm't #	Compliant	Not Compliant	Incomplete	Comments
4.3-1.a	☐	☐	☐	
4.3-1.b	☐	☐	☐	
4.3-2	☐	☐	☐	
4.4-1	[Hatched Pattern]			
4.4-2	☐	☐	☐	
4.4-3	☐	☐	☐	
4.4-4	☐	☐	☐	
4.5-1	☐	☐	☐	
4.5-2	☐	☐	☐	
4.6-1(a)	☐	☐	☐	
4.6-1(b)	☐	☐	☐	
4.6-1(c)	☐	☐	☐	
4.6-2	☐	☐	☐	
4.6-3	☐	☐	☐	
4.6-4	☐	☐	☐	
4.7-1	☐	☐	☐	
4.8-1	☐	☐	☐	

Additional Comments:

Reviewed by: _____ on: ____/____/____

Figure B.2-2: In-Flight, Pre-Decommissioning, and Pre-Disposal EOMP Review Check Sheet