Radiation Data Acquisition Satellite

Orbital Debris Assessment Report (ODAR)

This report complies with NASA-STD-8719.14, Appendix A, in accordance with NPR 8715.6B

Report Version: 1, 11/26/2017

DAS Version Used in This Analysis: 2.0

Embry-Riddle Aeronautical University

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Record of Revisions				
Rev	**Date**	**Affected Pages**	**Description of Change**	**Author(s)**
1	11/26/2017	All	Initial Release	Cody Sydnor, Gauge Frank, Jonathon Clark

Table of Contents

Self-assessment of the ODAR using the format in Appendix A.2 of NASA-STD-8719.14:

A self-assessment is provided below in accordance with the assessment format provided in Appendix A.2 of NASA-STD-8715.6B.

Orbital Debris Assessment Report Evaluation: RADSat Mission

Requirement #	Launch Vehicle				Spacecraft			Comments
	Compliant	Not Compliant	Incomplete	Standard Non Compliant	Compliant	Not Compliant	Incomplete	
4.3-1.a			x		x			No Debris released in LEO. See note 1.
4.3-1.b			x		x			No Debris released in LEO. See note 1.
4.3.2			x		x			No Debris released in GEO. See note 1.
4.4-1			x					See note 1.
4.4-2			x					See note 1.
4.4-3			x		x			No planned breakups. See note 1.
4.4-4			x		x			No planned breakups. See note 1.
4.5-1			x		x			See note 1.
4.5-2			x		x			See note 1.
4.6-1(a)			x		x			See note 1.
4.6-1(b)			x		x			See note 1.
4.6-1(c)			x		x			See note 1.
4.6-2			x		x			See note 1.
4.6-3			x		x			See note 1.
4.6-4			x					See note 1.
4.6-5			x					See note 1.
4.7-1			x		x			See note 1.
4.8-1					x			No tethers used.

Notes:

1. RADSat is a secondary payload being launched by NanoRacks, LLC. This ODAR is only for the RADSat payload and no other portions belong to other parties.

Assessment Report Format:

This ODAR follows the format in NASA-STD-8719.14, Appendix A.1 and includes the content indicated at a minimum in each section 2 through 8 below for the RADSat satellite. Sections 9 through 14 apply to the launch vehicle ODAR and are not covered here.

ODAR Section 1: Project Management and Mission Overview

RADSat Principle Investigator: Troy Henderson

Project Manager: Maxx Miller

Foreign Government or Space Agency Participation: None

Launch Date: 2019

Launch Site: USA

Launch Vehicle: N/A

Mission Description:

The Spacecraft Development Club of Embry-Riddle Aeronautical University, in Daytona Beach, Florida, is developing a 1U CubeSat for launch in 2019, which is called the Radiation Data Acquisition Satellite (RADSat). The payload of the small satellite is the Highly Miniaturized Radiation Monitor (HMRM), developed and delivered by European researchers at the Delft University of Technology in the Netherlands. The goals of the mission are to (1) return data from the HMRM which demonstrates its ability to operate in the space environment, and (2) return satellite telemetry which, when combined with the radiation data, will be useful when investigating computer faults and integrating the data into current simulation models. The CubeSat will be launched from the International Space Station (ISS) CubeSat Deployer, developed and maintained by NanoRacks LLC.

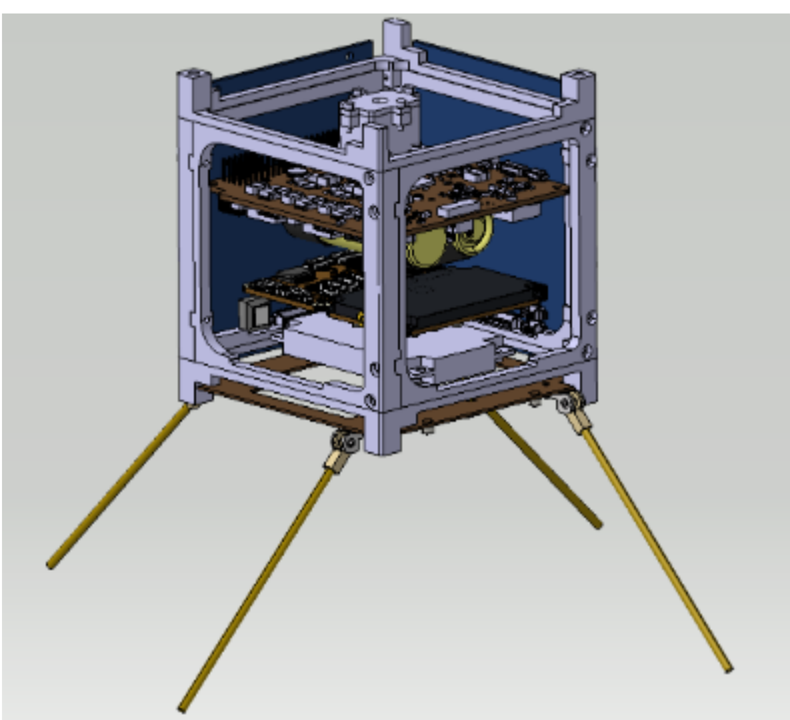

Figure 1: RADSat Isometric View with Antennas Deployed

Mission duration: 8-10 months

Launch and deployment profile, including all parking, transfer, and operational orbits, with apogee, perigee, and inclination:

RADSat will be launched and transported to the ISS. It will then be deployed from the NanoRacks CubeSat Deployer. RADSat will be launched into a circular orbit of approximately 400 km altitude.

The RADSat orbit is defined as follows:

Apogee: 407.0 km

Perigee: 402.0 km

Inclination: 51.64 degrees

RADSat has no propulsion and therefore is incapable of performing orbital maneuvers.

Reason for selected orbit:

The launch provider for RADSat is NanoRacks which only deploys spacecraft from the ISS.

Interaction or potential physical interference with other operational spacecraft:

RADSat will be deployed from the ISS and may be deployed simultaneously with other CubeSats, but should otherwise have no interaction with other operational spacecraft.

ODAR Section 2: Spacecraft Description

Physical description of the spacecraft:

RADSat will fit a 1U form factor. Basic dimensions are 10 cm x 10 cm x 10 cm with a mass of approximately 1 kg (exact mass to be determined).

RADSat will have four antennas that will be deployed after the spacecraft is launched from the ISS (See Figure 1). Any modifications to the antenna design will be announced to the FCC.

Total satellite mass at launch, including all propellants and fluids: Approximately 1 kg

Dry satellite mass at launch, excluding solid rocket motor propellants: Approximately 1 kg

Description of all propulsion systems (cold gas, mono-propellant, bi-propellant, electric, nuclear): None

Identification, including mass and pressure, of all fluids (liquids and gases) planned to be on board: None

Description of the fluid loading plan or strategies, excluding fluids in sealed heat pipes: None

Description of all fluid systems, including size, type, and qualifications of fluid containers such as propellant and pressurization tanks, including pressurized batteries: None

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:

RADSat will employ a passive magnetic stabilization ADCS. RADSat will utilize one permanent magnet cast from an 80% nickel-iron-molybdenum alloy and the interaction of the Earth's magnetic field with onboard hysteresis rods for attitude control. This will produce a torque that attempts to align the Z-axis of the spacecraft along the Earth's magnetic field. This should result in the Z-axis being aligned approximately in the normal/anti-normal direction relative to the velocity vector. The spacecraft will rotate continuously about the Z-axis as no roll control will be implemented.

Description of any range safety or other pyrotechnic devices: None

Description of the electrical generation and storage system:

RADSat will have 4 solar panels located on the +X, -X, +Y, and -Y faces of the spacecraft. Each panel will consist of 2 solar cells and produce… [power amount will be included in a future revision]. Power will be stored in a GOMSpace NanoPower P31u which will store 20 W of energy and operate at 8 V.

Identification of any other sources of stored energy not noted above: None

Identification of any radioactive materials on board or make a positive statement that there are no radioactive materials onboard:

RADSat will not have any 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: None

Rationale/necessity for release of each object: N/A.

Time of release of each object, relative to launch time: N/A.

Release velocity of each object with respect to spacecraft: N/A. **Expected orbital parameters (apogee, perigee, and inclination) of each object after release:** N/A

Calculated orbital lifetime of each object, including time spent in Low Earth Orbit (LEO): N/A

Assessment of spacecraft compliance with Requirements 4.3-1 and 4.3-2 (per DAS v2.0):

Requirement 4.3-1: *Debris passing through LEO – released debris with diameters of 1 mm 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**).

   Analysis: The spacecraft itself will be the only object released. According to the NASA Debris Assessment Software (DAS) the spacecraft will deorbit in approximately 2.3 years due to orbital decay.

b. Requirement 4.3-1b: The total object-time product shall be no larger than 100 object-years per mission (**Requirement 56399**).

   Analysis: Including the spacecraft itself, the total object-time for the mission is expected to be 2.3 object-years.

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**).

Analysis: The mission will not leave any debris traversing GEO.

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

Potential causes of spacecraft breakup during deployment and mission operations:

There are no known potential causes for spacecraft breakup during deployment or mission operations.

Summary of failure modes and effect analysis of all credible failure modes which may lead to an accidental explosion:

In-mission failure of a battery cell protection circuit could lead to a short circuit resulting in overheating and a remote possibility of battery cell explosion. The battery safety systems discussed in the FMEA (see requirement 4.4-1 below) describe the combined faults that must occur for any of seven (7) independent, mutually exclusive failure modes to lead to explosion.

Detailed plan for any designed spacecraft breakup, including explosions and intentional collisions:

There are no planned breakups.

List of components which shall be passivated at End of Mission (EOM) including method of passivation and amount which cannot be passivated:

RADSat will have no components that will need to be passivated at EOM. The CubeSat will breakup in atmospheric reentry.

Rationale for all items which are required to be passivated, but cannot be due to their design:

It was deemed unnecessary to passivate any components for EOM, as the CubeSat is small and will break up on re-entry at the end of the mission.

Assessment of spacecraft compliance with Requirement 4.4-1 through 4.4-4:

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**)
>
> **Analysis:** There are no known potential causes of an explosion onboard RADSat.
>
> **Required Probability:** 0.001.
>
> **Expected Probability:** <0.001.
>
> **Supporting Rational and FMEA details:**
>
> *Battery explosion:*
>
> **Effect:** All failure modes below might result in battery explosion with the possibility of orbital debris generation. However, in the unlikely event that a battery cell does explosively

rupture, the small size, mass, and potential energy, of these small batteries is such that while the spacecraft could be expected to vent gases, most debris from the battery rupture should be contained within the vessel due to the lack of penetration energy.

Probability: Extremely low. It is believed to be less than 0.001% given that that multiple independent (not common mode) faults must occur for each failure mode to cause the ultimate effect (explosion).

Failure Mode 1: Internal short circuit.

Mitigation 1: Qualification and acceptance shock, vibration, thermal cycling, and vacuum tests followed by maximum system rate-limited charge and discharge to prove that no internal short circuit sensitivity exists.

Combined faults required for realized failure: Environmental testing AND functional charge/discharge tests must both be ineffective in discovery of the failure mode.

Failure Mode 2: Internal thermal rise due to high load discharge rate.

Mitigation 2: Cells were tested in lab for high load discharge rates in a variety of flight like configurations to determine if the feasibility of an out of control thermal rise in the cell. Cells were also tested in a hot environment to test the upper limit of the cells capability. No failures were seen.

Combined faults required for realized failure: Spacecraft thermal design must be incorrect AND external over current detection and disconnect function must fail to enable this failure mode.

Failure Mode 3: Excessive discharge rate or short circuit due to external device failure or terminal contact with conductors not at battery voltage levels (due to abrasion or inadequate proximity separation).

Mitigation 3: This failure mode is negated by a) qualification tested short circuit protection on each external circuit, b) design of battery packs and insulators such that no contact with nearby board traces is possible without being caused by some other mechanical failure, c) obviation of such other mechanical failures by proto-qualification and acceptance environmental tests (shock, vibration, thermal cycling, and thermal-vacuum tests).

Combined faults required for realized failure: An external load must fail/short-circuit **AND** external over-current detection and disconnect function must all occur to enable this failure mode.

Failure Mode 4: Inoperable vents.

Mitigation 4: Battery vents are not inhibited by the battery holder design or the spacecraft.

Combined effects required for realized failure: The manufacturer fails to install proper venting.

Failure Mode 5: Crushing.

Mitigation 5: This mode is negated by spacecraft design. There are no moving parts in the proximity of the batteries.

Combined faults required for realized failure: A catastrophic failure must occur in an external system AND the failure must cause a collision sufficient to crush the batteries leading to an internal short circuit AND the satellite must be in a naturally sustained orbit at the time the crushing occurs.

Failure Mode 6: Low level current leakage or short-circuit through battery pack case or due to moisture-based degradation of insulators.

Mitigation 6: These modes are negated by a) battery holder/case design made of non-conductive plastic, and b) operation in vacuum such that no moisture can affect insulators.

Combined faults required for realized failure: Abrasion or piercing failure of circuit board coating or wire insulators AND dislocation of battery packs AND failure of battery terminal insulators AND failure to detect such failures in environmental tests must occur to result in this failure mode.

Failure Mode 7: Excess temperatures due to orbital environment and high discharge combined.

Mitigation 7: The spacecraft thermal design will negate this possibility. Thermal rise has been analyzed in combination with space environment temperatures showing that batteries do not exceed normal allowable operating temperatures which are well below temperatures of concern for explosions.

Combined faults required for realized failure: Thermal analysis AND thermal design AND mission simulations in thermal-vacuum chamber testing AND over-current monitoring and control must all fail for this failure mode to occur.

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**).

Analysis: RADSat will have no components that will need to be passivated.

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**).

Analysis: N/A, no planned explosions or intentional collisions are planned

b. Not generate debris larger than 1 mm that remains in Earth orbit longer than one year (**Requirement 56454).**

Analysis: N/A, no planned explosions or intentional collisions are planned

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).**

Analysis: N/A, no planned explosions or intentional collisions are planned.

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

Assessment of spacecraft compliance with Requirement 4.5-1 and 4.5-2 (per DAS v2.0 and calculation methods provided in NASA-STD-8719.14, section 4.5.4):

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**).

Large Object Impact and Debris Generation Probability: <0.001; COMPLIANT

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**).

Small Object Impact and Debris Generation Probability: <0.001; COMPLIANT

Identification of all systems or components required to accomplish any postmission disposal operation, including passivation and maneuvering: None

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

6.1 Description of Spacecraft disposal option selected: The satellite will de-orbit naturally by atmospheric re-entry. There is no propulsion system.

6.2 Plan for any spacecraft maneuvers required to accomplish post mission disposal: None

6.3 Calculation of area-to-mass ratio after post mission disposal, if the controlled reentry option is not selected:

Spacecraft Mass: 1 kg

Cross-sectional Area: 0.01 m^2

Area to mass ratio: 0.01 m^2/kg

6.4 Assessment of spacecraft compliance with Requirements 4.6-1 through 4.6-5 (per DAS v2.1.1 and NASA-STD- 8715.6B section):

Assessment of spacecraft compliance with Requirements 4.6-1 through 4.6-5 (per DAS v2.0 and NASA-STD-8719.14 section 4.6.3):

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 46557**)

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.

Analysis: According to DAS, the spacecraft will deorbit in approximately 340 days due to natural forces.

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**).

Analysis: Not applicable. RADSat orbit is LEO.

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**).

Analysis: Not applicable. RADSat orbit is LEO.

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.

   Analysis: RADSat is expected to deorbit due to natural forces approximately 340 days after launch and so a 1.00 probability of a successful disposal is expected.

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.

   Analysis: N/A, RADSat will deorbit due to natural forces.

ODAR Section 7: Assessment of Spacecraft Reentry Hazards

Assessment of spacecraft compliance with Requirement 4.7-1

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**).

Analysis (per DAS v2.1.1):

```
 11 16 2017; 13:43:30PM Activity Log Started
 11 16 2017; 13:43:30PM Opened Project C:\DAS2.1.1\
 11 16 2017; 13:43:38PM Processing Requirement 4.3-1:
Return Status: Not Run

=====================
 No Project Data Available
 =====================

=============== End of Requirement 4.3-1 ===============
 11 16 2017; 13:43:41PM Processing Requirement 4.3-2: Return
Status: Passed

=====================
 No Project Data Available
 =====================

=============== End of Requirement 4.3-2 ===============
 11 16 2017; 13:43:42PM Requirement 4.4-3:  Compliant

=============== End of Requirement 4.4-3 ===============
 11 16 2017; 13:46:41PM Processing Requirement 4.5-1:
Return Status :  Passed

==============
 Run Data
 ==============

**INPUT**

      Space Structure Name = RADSat
       Space Structure Type = Payload
       Perigee Altitude = 402.000000 (km)
       Apogee Altitude = 407.000000 (km)
       Inclination = 51.641400 (deg)
       RAAN = 0.000000 (deg)
       Argument of Perigee = 0.000000 (deg)
       Mean Anomaly = 0.000000 (deg)
       Final Area-To-Mass Ratio = 0.010000 (m^2/kg)
       Start Year = 2019.000000 (yr)
       Initial Mass = 1.000000 (kg)
       Final Mass = 1.000000 (kg)
       Duration = 0.500000 (yr)
       Station-Kept = False
       Abandoned = True
       PMD Perigee Altitude = -1.000000 (km)
       PMD Apogee Altitude = -1.000000 (km)
       PMD Inclination = 0.000000 (deg)
       PMD RAAN = 0.000000 (deg)
       PMD Argument of Perigee = 0.000000 (deg)
       PMD Mean Anomaly = 0.000000 (deg)

**OUTPUT**

      Collision Probability = 0.000000
       Returned Error Message: Normal Processing
       Date Range Error Message: Normal Date Range
       Status = Pass
```

```
==============

=============== End of Requirement 4.5-1 ===============
 11 16 2017; 13:48:17PM Requirement 4.5-2:  Compliant

==================================================
 Spacecraft = RADSat
 Critical Surface = +X
 ==================================================

**INPUT**

      Apogee Altitude = 407.000000 (km)
       Perigee Altitude = 402.000000 (km)
       Orbital Inclination = 51.641400 (deg)
       RAAN = 0.000000 (deg)
       Argument of Perigee = 0.000000 (deg)
       Mean Anomaly = 0.000000 (deg)
       Final Area-To-Mass = 0.010000 (m^2/kg)
       Initial Mass = 1.000000 (kg)
       Final Mass = 1.000000 (kg)
       Station Kept = No
       Start Year = 2019.000000 (yr)
       Duration = 0.500000 (yr)
       Orientation = Random Tumbling
       CS Areal Density = 0.421500 (g/cm^2)
       CS Surface Area = 0.010000 (m^2)
       Vector = (0.000000 (u), 0.000000 (v), 0.000000 (w))
       CS Pressurized = No

**OUTPUT**

      Probability of Penetration = 0.000311 (0.000311)
       Returned Error Message: Normal Processing
       Date Range Error Message: Normal Date Range

==================================================
 Spacecraft = RADSat
 Critical Surface = -X
 ==================================================

**INPUT**

      Apogee Altitude = 407.000000 (km)
       Perigee Altitude = 402.000000 (km)
       Orbital Inclination = 51.641400 (deg)
       RAAN = 0.000000 (deg)
       Argument of Perigee = 0.000000 (deg)
       Mean Anomaly = 0.000000 (deg)
       Final Area-To-Mass = 0.010000 (m^2/kg)
       Initial Mass = 1.000000 (kg)
       Final Mass = 1.000000 (kg)
       Station Kept = No
       Start Year = 2019.000000 (yr)
       Duration = 0.500000 (yr)
       Orientation = Random Tumbling
       CS Areal Density = 0.421500 (g/cm^2)
       CS Surface Area = 0.010000 (m^2)
       Vector = (0.000000 (u), 0.000000 (v), 0.000000 (w))
```

```
       CS Pressurized = No

**OUTPUT**

      Probability of Penetration = 0.000311 (0.000311)
       Returned Error Message: Normal Processing
       Date Range Error Message: Normal Date Range

==================================================
 Spacecraft = RADSat
 Critical Surface = +Y
 ==================================================

**INPUT**

      Apogee Altitude = 407.000000 (km)
       Perigee Altitude = 402.000000 (km)
       Orbital Inclination = 51.641400 (deg)
       RAAN = 0.000000 (deg)
       Argument of Perigee = 0.000000 (deg)
       Mean Anomaly = 0.000000 (deg)
       Final Area-To-Mass = 0.010000 (m^2/kg)
       Initial Mass = 1.000000 (kg)
       Final Mass = 1.000000 (kg)
       Station Kept = No
       Start Year = 2019.000000 (yr)
       Duration = 0.500000 (yr)
       Orientation = Random Tumbling
       CS Areal Density = 0.421500 (g/cm^2)
       CS Surface Area = 0.010000 (m^2)
       Vector = (0.000000 (u), 0.000000 (v), 0.000000 (w))
       CS Pressurized = No

**OUTPUT**

      Probability of Penetration = 0.000311 (0.000311)
       Returned Error Message: Normal Processing
       Date Range Error Message: Normal Date Range

==================================================
 Spacecraft = RADSat
 Critical Surface = -Y
 ==================================================

**INPUT**

      Apogee Altitude = 407.000000 (km)
       Perigee Altitude = 402.000000 (km)
       Orbital Inclination = 51.641400 (deg)
       RAAN = 0.000000 (deg)
       Argument of Perigee = 0.000000 (deg)
       Mean Anomaly = 0.000000 (deg)
       Final Area-To-Mass = 0.010000 (m^2/kg)
       Initial Mass = 1.000000 (kg)
       Final Mass = 1.000000 (kg)
       Station Kept = No
       Start Year = 2019.000000 (yr)
       Duration = 0.500000 (yr)
       Orientation = Random Tumbling
```

```
        CS Areal Density = 0.421500 (g/cm^2)
        CS Surface Area = 0.010000 (m^2)
        Vector = (0.000000 (u), 0.000000 (v), 0.000000 (w))
        CS Pressurized = No

**OUTPUT**

       Probabilty of Penetration = 0.000311 (0.000311)
        Returned Error Message: Normal Processing
        Date Range Error Message: Normal Date Range

==================================================
 Spacecraft = RADSat
 Critical Surface = +Z
 ==================================================

**INPUT**

       Apogee Altitude = 407.000000 (km)
        Perigee Altitude = 402.000000 (km)
        Orbital Inclination = 51.641400 (deg)
        RAAN = 0.000000 (deg)
        Argument of Perigee = 0.000000 (deg)
        Mean Anomaly = 0.000000 (deg)
        Final Area-To-Mass = 0.010000 (m^2/kg)
        Initial Mass = 1.000000 (kg)
        Final Mass = 1.000000 (kg)
        Station Kept = No
        Start Year = 2019.000000 (yr)
        Duration = 0.500000 (yr)
        Orientation = Random Tumbling
        CS Areal Density = 0.421500 (g/cm^2)
        CS Surface Area = 0.010000 (m^2)
        Vector = (0.000000 (u), 0.000000 (v), 0.000000 (w))
        CS Pressurized = No

**OUTPUT**

       Probabilty of Penetration = 0.000311 (0.000311)
        Returned Error Message: Normal Processing
        Date Range Error Message: Normal Date Range

==================================================
 Spacecraft = RADSat
 Critical Surface = -Z
 ==================================================

**INPUT**

       Apogee Altitude = 407.000000 (km)
        Perigee Altitude = 402.000000 (km)
        Orbital Inclination = 51.641400 (deg)
        RAAN = 0.000000 (deg)
        Argument of Perigee = 0.000000 (deg)
        Mean Anomaly = 0.000000 (deg)
        Final Area-To-Mass = 0.010000 (m^2/kg)
        Initial Mass = 1.000000 (kg)
        Final Mass = 1.000000 (kg)
        Station Kept = No
```

```
        Start Year = 2019.000000 (yr)
        Duration = 0.500000 (yr)
        Orientation = Random Tumbling
        CS Areal Density = 0.421500 (g/cm^2)
        CS Surface Area = 0.010000 (m^2)
        Vector = (0.000000 (u), 0.000000 (v), 0.000000 (w))
        CS Pressurized = No

**OUTPUT**

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        Date Range Error Message: Normal Date Range


11 16 2017; 13:49:45PM Processing Requirement 4.6   Return
Status :  Passed

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 Project Data
 ==============

**INPUT**

       Space Structure Name = RADSat
        Space Structure Type = Payload

       Perigee Altitude = 402.000000 (km)
        Apogee Altitude = 407.000000 (km)
        Inclination = 51.641400 (deg)
        RAAN = 0.000000 (deg)
        Argument of Perigee = 0.000000 (deg)
        Mean Anomaly = 0.000000 (deg)
        Area-To-Mass Ratio = 0.010000 (m^2/kg)
        Start Year = 2019.000000 (yr)
        Initial Mass = 1.000000 (kg)
        Final Mass = 1.000000 (kg)
        Duration = 0.500000 (yr)
        Station Kept = False
        Abandoned = True
        PMD Perigee Altitude = 396.765798 (km)
        PMD Apogee Altitude = 400.451261 (km)
        PMD Inclination = 51.637869 (deg)
        PMD RAAN = 167.347455 (deg)
        PMD Argument of Perigee = 181.435281 (deg)
        PMD Mean Anomaly = 0.000000 (deg)

**OUTPUT**

       Suggested Perigee Altitude = 396.765798 (km)
        Suggested Apogee Altitude = 400.451261 (km)
        Returned Error Message = Passes LEO reentry orbit
criteria.

       Released Year = 2021 (yr)
        Requirement = 61
        Compliance Status = Pass

==============
```

```
============== End of Requirement 4.6 ==============
 11 16 2017; 13:49:57PM *********Processing Requirement 4.7-1
       Return Status :  Passed

***********INPUT****
  Item Number = 1

name = RADSat
 quantity = 1
 parent = 0
 materialID = 9
 type = Box
 Aero Mass = 1.000000
 Thermal Mass = 1.000000
 Diameter/Width = 0.100000
 Length = 0.100000
 Height = 0.100000

name = R
 quantity = 1
 parent = 1
 materialID = 9
 type = Box
 Aero Mass = 1.000000
 Thermal Mass = 1.000000
 Diameter/Width = 0.100000
 Length = 0.100000
 Height = 0.100000

**************OUTPUT****
 Item Number = 1

name = RADSat
 Demise Altitude = 77.992470
 Debris Casualty Area = 0.000000
 Impact Kinetic Energy = 0.000000

*************************************
 name = R
 Demise Altitude = 67.319862
 Debris Casualty Area = 0.000000
 Impact Kinetic Energy = 0.000000

*************************************

============== End of Requirement 4.7-1 ==============
```

ODAR Section 8: Assessment for Tether Missions

Assessment of spacecraft compliance with Requirement 4.8-1

Requirement 4.8-1. Mitigate the collision hazards for 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**).

Analysis: N/A, spacecraft has no tethers