Attachment A

Orbital Debris Assessment

Orbital Debris Assessment

Compliance Summary

Requirement	Compliant	Commentary
47 C.F.R. § 5.64(b)(1)	Yes	K2 Space confirms that the Spacecraft will not undergo any planned release of debris during normal operations. In addition, all separation and deployment mechanisms, and any other potential source of debris, will be retained by the Spacecraft.
47 C.F.R. § 5.64(b)(2)	Yes	K2 Space has assessed the probability of the Spacecraft becoming a source of debris by collision with small debris or meteoroids of less than one centimeter in diameter that could cause loss of control and prevent post-mission disposal, as discussed in more detail below. K2 Space has taken steps to limit the effects of such collisions through shielding, the placement of components, and the use of redundant systems. The analysis was conducted pursuant to NASA-STD-8719.14C Section 4.5-2, as is further discussed below.
47 C.F.R. § 5.64(b)(3)	Yes	K2 Space has assessed and limited the probability of accidental explosions during and after completion of mission operations through a failure-mode verification analysis. As part of the satellite manufacturing process, K2 Space has taken steps to ensure that debris generation will not result from the conversion of energy sources on board the Spacecraft into energy that fragments the Spacecraft. All sources of stored energy onboard the Spacecraft will be depleted or safely contained when no longer required for mission operations or post-mission disposal. To passivate the spacecraft, all Krypton propellent onboard will be vented, and batteries will be depleted below 5% state of charge.
47 C.F.R. § 5.64(b)(4)	Yes	K2 Space has assessed and limited the probability of the Spacecraft becoming a source of debris by collisions with large debris or other operational spacecraft, as discussed below in more detail. K2 Space will work closely with its launch providers to ensure that the spacecraft is deployed in such a way as to minimize the potential for in-plane collision.
47 C.F.R. § 5.64(b)(4)(i)(A)	Yes	The analysis was conducted pursuant to NASA-STD-8719.14C Section 4.5-1, as is further discussed below
47 C.F.R. § 5.64(b)(4)(i)(B)	Yes	With respect to MEO orbits, K2 Space has examined industry-standard, publicly available information and confirms that the Spacecraft’s orbit will not interfere with the orbits of current or future known MEO operating spacecraft, including spacecraft from O3b, Galileo, GPS, and GLONASS.
47 C.F.R. § 5.64(b)(4)(i)(C)	N/A	The spacecraft is not expected to traverse through the orbit of any inhabitable spacecraft.
47 C.F.R. § 5.64(b)(4)(i)(D)	Yes	The spacecraft has a propulsion system and is maneuverable.

		Apogee and perigee will both be maintained within 50 km from the targeted altitude. All other orbital parameters will not be actively maintained.
47 C.F.R. § 5.64(b)(4)(i)(E)	Yes	K2 Space certifies that upon receipt of a space situational awareness conjunction warning, it will review and take all possible steps to assess the collision risk, including but not limited to: contacting the operator of any active spacecraft involved in such a warning; sharing ephemeris data and other appropriate operational information with any such operator; and modifying space station attitude and/or operations.
47 C.F.R. § 5.64(b)(4)(ii)	N/A	Not Applicable – Not requesting geostationary orbit
47 C.F.R. § 5.64(b)(5)	Yes	K2 Space will register and participate in a sharing agreement with the 18th Space Defense Squadron ("18th SDS") to better coordinate collision avoidance measures and receive conjunction threat report. The Spacecraft will carry onboard GPS receivers that provide for precise orbital position determination. K2 Space will also receive from the 18th SDS updated two-line element sets, or "TLEs," which facilitate the identification and tracking of the Spacecraft.
47 C.F.R. § 5.64(b)(5)(i)	Yes	K2 Space will passively track the spacecraft. Prior to deployment, the launch vehicle provider will provide an initial ephemeris and a more accurate ephemeris post-deployment. Once ground station contact is established, satellite tracking from ground station as well as downlinked telemetry will provide enhanced ephemeris data.
47 C.F.R. § 5.64(b)(5)(ii)	Yes	K2 Space will register and participate in a sharing agreement with the 18th SDS prior to deployment.
47 C.F.R. § 5.64(b)(5)(iii)	Yes	K2 Space will register and participate in a sharing agreement with the 18th SDS prior to deployment.
47 C.F.R. § 5.64(b)(6)	N/A	Not Applicable – There are no planned proximity operations
47 C.F.R. § 5.64(b)(7)	Yes	The disposal is planned in the following orbital parameters: altitude: 7800 km, eccentricity: 0, inclination: 50 degrees. 200 kg of propellent will be reserved for orbit raise to the disposal orbit.
47 C.F.R. § 5.64(b)(7)(i)	N/A	Not Applicable – Not requesting geostationary orbit
47 C.F.R. § 5.64(b)(7)(ii)	N/A	Not Applicable – Not terminating in LEO region
47 C.F.R. § 5.64(b)(7)(iii)	Yes	The Spacecraft will use a storage orbit. The analysis was conducted pursuant to NASA-STD-8719.14C Section 4.6-2, as is discussed further below.
47 C.F.R. § 5.64(b)(7)(iv)(A)	Yes	The probability of success of achieving the disposal orbit is greater than 0.9. The analysis was conducted pursuant to NASA-STD-8719.14C Section 4.6-4, as is discussed further below.
47 C.F.R. § 5.64(b)(7)(iv)(B)	N/A	Not Applicable – disposal is not via atmospheric entry

Supporting Explanations

47 C.F.R. § 5.64(b)(2)

Requirement: *A statement indicating whether the space station operator has assessed and limited the probability that the space station(s) will become a source of debris by collision with small debris or meteoroids that would cause loss of control and prevent disposal. The statement must indicate whether this probability for an individual space station is 0.01 (1 in 100) or less, as calculated using the NASA Debris Assessment Software or a higher fidelity assessment tool.*

Compliance Statement: The probability that the spacecraft will become a source of debris by collision with small debris or meteoroids is 6.2404E-04. This is compliant with NASA-STD-8719.14C Section 4.5-2. K2 Space used the DAS 3.2.6 tool for this analysis.

Analysis:

All components on the spacecraft were evaluated to determine if they are vital to completing the post-mission disposal.[1] Of the components on the Spacecraft, the Flight Computer and Propulsion System were determined as vital systems requiring evaluation. Within the propulsion system, only the propulsion tanks were identified as vital, given the power propulsion unit ("PPU") and thruster are fully 1-fault tolerant with 2 separate units able to complete the post mission disposal.

All vital components for post mission disposal are housed within the aluminum primary structure of the bus with a minimum of 3mm of shielding.

K2 Space examined compliance with NASA-STD-8719.14C Section 4.5-2 for 2 vital components with DAS 3.2.6 tool using the following characteristics:

<u>Flight Computer</u>

Payload Orientation: Gravity Gradient

<u>Critical Surface</u>	
Areal Density (g/cm^2)	0.309
Surface Area (m^2)	0.149
Unit Normal Vector (UVW)	0-1-0
Pressurized	No
<u>Outer Walls</u>	
Areal Density (g/cm^2)	0.81
Separation (cm)	1
Areal Density (g/cm^2)	0.81
Separation (cm)	0.3

[1] *See* NASA-STD-8719.14C 4.5.4.3.3. Only subsystems which are vital to completing post-mission disposal need to be addressed.

Propulsion Tanks

Payload Orientation: Gravity Gradient

Critical Surface	
Areal Density (g/cm^2)	2.61
Surface Area (m^2)	0.6747
Unit Normal Vector (UVW)	0-1-0
Pressurized	Yes
Outer Walls	
Areal Density (g/cm^2)	0.81
Separation (cm)	2.24

Initial Orbit: 500 km

Assumptions:

- Time (yrs): 0.07 (equivalent to ~4 weeks)
- Op Perigee (km): 500
- Op Apogee (km): 500

Results:

Subsystem	P
Tanks	3.033E-04
Flight Computer	2.412E-04

The probability that any component fails at 500 km is 5.445E-04

Second Orbit: 7800 km

Assumptions:

- Time (yrs): 3
- Op Perigee (km): 7800
- Op Apogee (km): 7800

Results:

Subsystem	P
Tanks	7.2000E-05
Flight Computer	7.5373E-06

The probability that any component fails at 7800 km is 7.9537E-05.

The combined probability across all orbital altitudes is 6.2404E-04.

47 C.F.R. § 5.64(b)(4)(i)(A)

Requirement: *A demonstration that the space station operator has assessed and limited the probability of collision between any space station of the system and other large objects (10 cm or larger in diameter) during the total orbital lifetime of the space station, including any de-orbit phases, to less than 0.001 (1 in 1,000). The probability shall be calculated using the NASA Debris Assessment Software or a higher fidelity assessment tool. The collision risk may be assumed zero for a space station during any period in which the space station will be maneuvered effectively to avoid colliding with large objects.*

Compliance Statement: The probability that the spacecraft will become a source of debris by collision with large objects at the disposal orbit is 8.9046E-05 This is compliant with NASA-STD-8719.14C Section 4.5-1. K2 Space used the DAS 3.2.6 tool for this analysis.

Analysis:

The spacecraft is maneuverable from orbital insertion to the end of life at the disposal altitude. As such, the collision risk is zero, as specified in 47 C.F.R. § 5.64(b)(4)(i)(A), during the active phase of the mission.

Notwithstanding the preceding, prior to launch, K2 Space will coordinate with the 18th SDS to share critical information about the propulsive and maneuverability capabilities of the Spacecraft.

If during the Trinity mission 18th SDS or K2 Space determines that there is a probability of collision larger than 1e-4, then K2 Space will take immediate remedial steps, including altering the orbit and/or trajectory of the Spacecraft. In the event that the spacecraft propulsion system is inoperable, K2 Space will employ differential drag of the solar arrays to perform debris avoidance maneuvers.

As specified in NASA-STD-8719.14C Section 4.5.2.3, the risk of collision was evaluated for 100 years using the DAS 3.2.6 tool. The following summarizes this exercise.

K2 Space assumed full mission duration at each operation altitude. We have reported the bounding case of all operational altitudes here:

Mission Duration (yrs): 100 years

Disposal Perigee Alt (km): 7800

Disposal Apogee Alt (km): 7800

Disposal Inclination (deg): 50

Final Mass (kg): 1800

Final Area-to-Mass (m^2/kg): 0.051

The results indicate a probability of 8.9046E-05, which is less than 0.001 and meets the requirement 4.5-1 from the DAS 3.2.6 tool that the probability be < 0.001.

47 C.F.R. § 5.64(b)(7)(iii)

Requirement: *For space stations not covered by either paragraph (b)(7)(i) or (ii) of this section, the statement must indicate whether disposal will involve use of a storage orbit or long-term atmospheric re-entry and rationale for the selected disposal plan.*

Compliance Statement: The spacecraft disposal will be between LEO and GEO in a near circular orbit. This is compliant with NASA-STD-8719.14C Section 4.6-2. K2 Space used the DAS 3.2.6 tool for this analysis.

Analysis:

With the spacecraft disposal between LEO and GEO zone, NASA-STD-8719.14C Sections 4.6-2 and 4.6.2.3(1)(2)[2] apply to the validation of the disposal orbit.

The spacecraft will be disposed in the following orbit.

- Disposal orbit altitude: 7800 km
- Disposal orbit eccentricity: 0
- Disposal orbit inclination: 50 degrees

This disposal orbit successfully avoids crossing 20,182 +/- 300km, the GEO zone, and LEO zone for at least 100 years. Utilizing NASA's DAS, compliance to a MEO disposal orbit is shown. The spacecraft orbit is stable over the minimum 100 years post end of mission.

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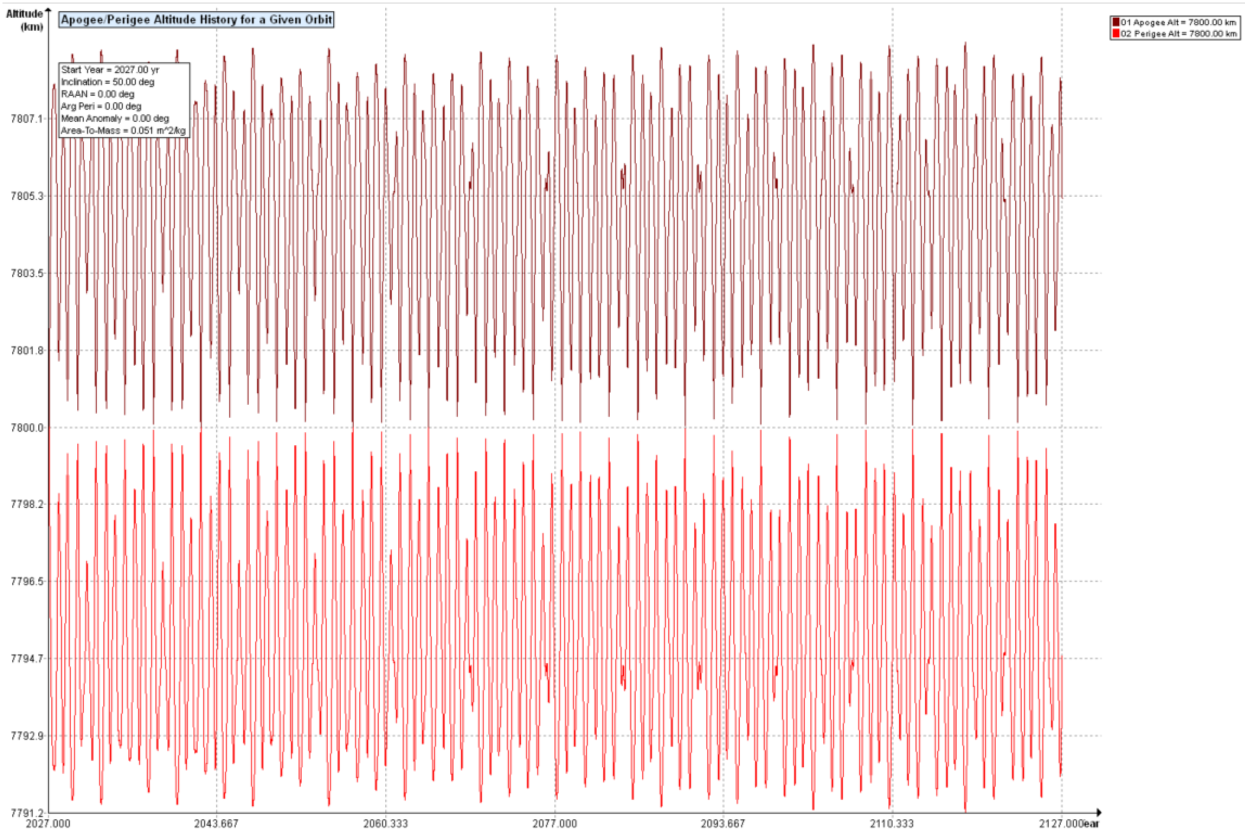
[2] *See* NASA-STD-8719.14C 4.6-2 section 4.6.2.3(1)(2). Maneuver to a near-circular disposal orbit to (i) avoid crossing 20,182 +/- 300 km, the GEO zone, and the LEO zone for at least 100 years, and (ii) limit the risk to other operational constellations, for example, by avoiding crossing the altitudes occupied by known missions of 10 or more spacecraft using near-circular orbits, for 100 years.



Furthermore, K2 Space has examined industry-standard, publicly available information and confirms that the Spacecraft's disposal orbit will limit the risk to other operational constellations and avoid crossing the altitudes occupied by known missions of 10 or more spacecraft using near-circular orbits, for 100 years, including specifically spacecraft from O3b, Galileo, GPS, and GLONASS constellations.

To reiterate, the selected orbit is very stable and will not decay to the LEO orbit range, nor will it approach the GSO, and the selected disposal orbit creates no possibility of collision with the O3b, GPS, Galileo or GLONASS MEO systems which are (or will be) all above 7800 km in altitude for at least 100 years.

47 C.F.R. § 5.64(b)(7)(iv)(A)

Requirement: *The statement must include a demonstration that the probability of success of the chosen disposal method will be 0.9 or greater for any individual space station. For space station systems consisting of multiple space stations, the demonstration should include additional information regarding efforts to achieve a higher probability of success, with a goal, for large systems, of a probability of success for any individual space station of 0.99 or better. For space stations under paragraph (b)(7)(ii) of this section that will be terminating operations in or passing through the low-Earth orbit region below 2000 km altitude, successful disposal is defined, for the purposes of this paragraph (b)(7)(iv)(A), as atmospheric re-entry of the spacecraft as soon as practicable, but no later than five years following completion of the mission. For space stations under paragraph (b)(7)(iii) of this section, successful disposal will be assessed on a case-by-case basis.*

Compliance Statement: The probability of success that the spacecraft will achieve its disposal orbit is 99.3%. This is compliant with NASA-STD-8719.14C Section 4.6-4.

Analysis:

The K2 Space Spacecraft is designed with fully 1-fault tolerant systems, which are each qualified and accepted to SMC-S-016 standards. This fault tolerant architecture in addition to usage of space-qualified components leads to an inherently reliable vehicle following industry best practices. In addition to the component and system level, the entire spacecraft will undergo environmental screening to validate its performance prior to launch.

Specific Failure modes and effects analysis (FMEA) was completed as specified in NASA-STD-8719.14C Section 4.6.4.3.1 evaluating risks, including both loss of control and failure of the post mission disposal system. The FMEA was performed evaluating the likelihood and consequence of each failure mode in the system to determine the overall risk. The criteria matrix for this evaluation method is shown below. Notably, only a severity ranking of 5 indicates risk to spacecraft disposal.

Occurrence Rankings

Likelihood of Occurrence	Criteria: Possible Failure Rates/Probability of Failure	Design Specific Score Criteria	Rating
Near Certainty	Likely to occur often during the duration of a mission99% >= x > 30%		5
Highly Likely	Highly likely to occur sometime during the duration of a mission30% >= x > 10%	- Any non-destructive SEE- TID induced behaviors	4
Likely	Likely to occur some time during the duration of a mission10% >= x > 1%		3
Low Likelihood	Unlikely, but possible to occur during the duration of a mission1% >= x > 0.1%		2
Not Likely	So unlikely, it can be assumed occurrence may not be experienced during the duration of a mission 0.1% >= x	- Any DSEE (all parts tested to LET_th levels to screen out components that will experience DSEE during mission duration) - Connector failures will have been screened out during environmental testing - Low likelihood of FOD present post environmental testing/launch/etc. because of conformal coat on all PCBAs	1

Severity Rankings

Effect	Criteria: Severity of Effect	Design Specific Score Criteria	Rating
Critical	Permanent loss of ability to achieve mission success criteria or safe spacecraft disposal per applicable regulation		5
Significant	Temporary loss of ability to achieve mission success criteria resulting in significant impact to customer operations; significant reduction in mission performance or lifetime		4
Moderate Lost Mission Time	Minor reduction in mission lifetime; permanent loss of redundancy for mission-critical functions		3
Minor	Temporary loss of redundancy for mission-critical functions, reduction in system margin		2
Minimal	No impacts to mission-critical functions, system performance, or margin		1

For the purposes of this analysis, only risks of severity 5 are shown given their relevance to evaluating the risk to disposal. Seven failure modes were evaluated, which met that criterion, each with an occurrence during the course of the mission of less than 0.1%. Assuming worst case independent probability of each failure mode occurring, the overall likelihood of failure is 0.7%. This provides the likelihood of successful disposal at 99.3%.

Subsystem/Componen	Potential Failure Mode	Potential Cause of Failure	Occurren	Potential Effects of Failure	Sever	Mitigating Factors
HV Battery	Loss of HV Battery - Erroneous Output, Overvoltage, HV	Runaway MPPT Converter Battery cell overcharge	1	A sustained, overvoltage condition on all HV battery outputs would lead to potential catastrophic fialure of downstream HV loads as well as potential full pack thermal runaway	5	All converters contain redundant over-voltage protection Multiple redundant over-voltage FDIR protections to prevent over-charging of the battery cells HV switches will provide some isolation of the over-voltage condition depending on the transient/duration.
HV Battery	Loss of HV Battery - Pack Thermal Runaway	Multiple Cell Thermal Runaway Failure of overcharge protection in battery pack Failure of overtemp protection in battery pack	1	Potential propagation to nearby redundant HV packs or other critical satellite systems. In the worst-case this could lead to complete loss of mission.	5	Battery designed to mitigate the effects of any single cell thermal runaway condition. Battery designed with multiple redundant over-charge and over-temp protection in both software and hardware.
Solar Array	Failure to deploy solar array wing	Mechanism failure, snag, binding, etc due to design flaw or environmental/performance qualification exceedance	1	Loss of 1/2 power generation capability, depending on the failure mode potential loss of attitude control and sufficient power generation capability to support mission.	5	Solar array mechanism is designed with redundancy where possible and high safety margins. Solar array mechanism undergoes full system level qualification and acceptance testing prior to flight to bound all environmental regimes for deployment with sufficient margin.
Solar Array Drive Assembly	Loss of SADA sun tracking capability	Mechanism failure, snag, binding, etc due to design flaw or environmental/performance qualification exceedance	1	Loss of 1/2 power generation capability, depending on the failure mode potential loss of attitude control and sufficient power generation capability to support mission.	5	SADA is designed to be fully fault tolerant with redundant motors, motor drive, sensors, etc.
Propulsion System	Failure of Tank or Tank Manifold - Leak/Rupture	Gross mechanical failure due to design flaw or environmental/perforance qualification exceedance	1	Potential loss of all onboard propellant leading to loss of orbit raise, station-keeping, and disposal capability	5	All mechanical joints are designed with appropriate structural safety factors, all threaded components leverage secondary retention, mechanical components analyzed and qualified for launch and on-orbit loads. Tanks qualified per AIAA-S-081B.
TT&C System	Loss of all S-band uplink capability	Persistent jamming, multiple electrical failures	1	Loss of all spacecraft commanding capability	5	Vehicle is designed with redundant, fault isolated radios, each of which has an independent network of S-band RF components and antenna. The S-band system is designed with multiple antennas to provide full omni-directional receive and transmit patterns for each radio. The vehicle also includes a separate X-band downlink system for higher rate telemetry.
GNC System	Loss of all GNSS Receivers	Persistent jamming, multiple electrical failures	1	Loss of all orbit determination capability	5	Multiple GNSS receivers with multiple antennas are leveraged to provide 2-pi steridian coverage. Each GNSS receiver is multi-band and multi-constellation and contains various anti-jam features to enhance system performance.