TECHNICAL APPENDIX

Application for Modification

This Technical Appendix supplements Amazon's original application for authorization.[1]

I. ORBITAL DEBRIS MITIGATION PLAN

Space safety is fundamental to Kuiper. Amazon's satellite design, and its operational strategies, will mitigate orbital debris risks, consistent with Section 25.114(d)(14) of the Commission's rules. When the Commission granted the *Kuiper System Authorization*, it conditioned the authorization on Amazon presenting, and the Commission approving, a modification application with an updated description of the final orbital debris mitigation plans for the Kuiper System.[2] The Commission explained that this updated plan should address in greater detail the collision[3] risk for the system as a whole (including consideration of the reliability of post-mission disposal and the effect of failed satellites on risk) and reentry casualty risk.[4] This orbital debris mitigation plan addresses the Commission's request for additional information,

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[1] The information provided in this Technical Appendix, submitted electronically as an attachment to FCC Form 312, updates and, to the extent inconsistent, replaces the orbital debris information in Amazon's original application, including information provided in Section II of the Technical Appendix, as supplemented. *See* Kuiper Systems LLC, SAT-LOA-20190704-00057 (filed July 4, 2019); Letter from C. Andrew Keisner, Lead Counsel, Kuiper Systems LLC, to Jose P. Albuquerque, Chief, Satellite Division—International Bureau, FCC, IBFS File No. SAT-LOA-20190704-00057 (Sept. 18, 2019). To the extent not otherwise indicated or reflected in this application or Amazon's pending modification, *see* Kuiper Systems LLC, SAT-MOD-20210806-00095 (filed Aug. 6, 2021), Amazon certifies that the information previously provided to the Commission in Amazon's original application is unchanged and incorporated by reference, *see* 47 C.F.R. § 25.117(c), (d)(1).

[2] *See In re Kuiper Systems LLC, Application for Authority to Deploy and Operate a Ka-band Non-Geostationary Satellite Orbit System*, Order and Authorization, 35 FCC Rcd 8324, 8333 ¶ 32, 8345 ¶ 64 (2020) ("*Kuiper System Authorization*"). Specifically, the Commission ordered Amazon to, "upon finalization of its space station design and prior to initiation of service, . . . seek and obtain the Commission's approval of a modification containing an updated description of the orbital debris mitigation plans for its system." *Id.* at 8345 ¶ 64. The non-geostationary satellite orbit system authorized by the *Kuiper System Authorization* is the "Kuiper System."

[3] In this document, Amazon uses the term "collision" to describe physical impact between two orbiting bodies and the term "conjunction" to describe the minimum distance event between two orbiting bodies involving significant proximity relative to their trajectory uncertainties.

[4] *See Kuiper System Authorization*, 35 FCC Rcd at 8333 ¶ 32 & n.74.

including system parameters and orbital debris mitigation measures with respect to Amazon's satellite design, and collision risk, including reliability of post-mission disposal[5] and the effect of failed satellites on risk,[6] and reentry casualty risk.[7]

Debris Release and Small Debris[8]

Amazon has assessed and limited the amount of debris released in a planned manner during normal operations. Kuiper Satellites[9] do not rely on mechanical release bands, breakaway mechanisms, or mechanical cutaway devices to release from the launch vehicle or to actuate deployable structures on the satellite. This approach limits the chance that debris will be released during normal deployment.

Kuiper Satellites will be launched into an initial deployment orbit at or near 400 km and raised to their operational altitude in one of three orbital shells, as shown in Table 1. Amazon has been coordinating with National Aeronautics and Space Administration's ("NASA") Johnson Space Center Trajectory Optimization and Planning Office ("NASA TOPO") since 2020 in relation to the International Space Station ("ISS") altitude plans, and to eliminate any potential flight hazards to human spaceflight with regard to Kuiper Satellite trajectories. Amazon will

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[5] *See* Post-Mission Disposal, *infra* at 14.

[6] *See* Collision With Large Objects, *infra* at 7.

[7] *See* Post-Mission Disposal, *infra* at 14.

[8] 47 C.F.R. § 25.114(d)(14)(i) (requiring "[a] statement that the space station operator has assessed and limited the amount of debris released in a planned manner during normal operations, and has assessed and limited the probability of the space station becoming a source of debris by collisions with small debris or meteoroids that could cause loss of control and prevent post-mission disposal").

[9] As used in this Technical Appendix, the term "Kuiper Satellites" refers to the satellites authorized by the Commission pursuant to the *Kuiper System Authorization*, 35 FCC Rcd 8324.

coordinate with NASA both on ascent and deorbit and will adjust the Kuiper Satellites' injection altitude accordingly.

Consistent with the Commission's rules, Amazon has also assessed and limited the probability that a Kuiper Satellite will become a source of debris by collisions with small debris or meteoroids that could cause loss of control and prevent post-mission disposal.[10] Amazon examined the following potential operational failure scenarios leading to loss of control:

1. A Kuiper Satellite is non-operational on release from the launch vehicle at 400 km, fails to deploy the solar arrays, and has a full beginning of mission ("BOM") mass.
2. A Kuiper Satellite successfully releases from the launch vehicle at 400 km, has deployed the solar panels, but fails shortly thereafter with full BOM mass before reaching its operational altitude.
3. A Kuiper Satellite is at its operational altitude with solar panels fully deployed with full BOM mass.

Using the NASA Debris Assessment Software ("DAS"),[11] Amazon calculated the passive deorbit period for each of these failure scenarios for each shell, as shown in Table 2. In all scenarios, a Kuiper Satellite deorbits in less than ten years due to atmospheric drag, even if all propulsive capability is lost. Because solar activity (and thus atmospheric drag) varies on a roughly 11-year cycle, and in order to review data through two solar cycles, Amazon also analyzed the deorbit periods assuming a launch as late as 2043. Under the failure scenarios shown in Table 2, a Kuiper Satellite would be expected to deorbit in a period of time ranging from approximately 26 days to 3.4 years (failure at insertion altitude), and 1.2 to 9 years (failure at operational altitude),

[10] *See Kuiper System Authorization*, 35 FCC Rcd 8324.

[11] DAS version 3.1.1 with solar flux file dated September 21, 2021.

with a worst-case deorbit period of approximately 9 years. Therefore, a failure during operations resulting in loss of the ability to perform the planned post-mission disposal maneuver activity would not prevent mission disposal within 25 years. The probability of a Kuiper Satellite becoming a long-term debris risk due to failure to re-enter is near zero.[12]

Table 1. Orbital Configuration

	Altitude [km]	**Inclination [deg]**
Shell 1	590	33
Shell 2	610	42
Shell 3	630	51.9

Table 2. Failure Scenario Reentry Analysis

Scenario Description	**Area/Mass [m^2/kg]**	**Altitude [km]**	**Inclination [deg]**	**Minimum Reentry Time [yrs]**	**Maximum Reentry Time [yrs]**
Insertion altitude,	0.00514	400	33	0.624	3.280
no solar panel deployment			42	0.635	3.340
			51.9	0.641	3.395
Insertion altitude,	0.04756	400	33	0.071	0.444
solar panels deployed			42	0.077	0.454
			51.9	0.077	0.460
Ops altitude,	0.04756	590	33	1.210	6.872
solar panels deployed		610	42	1.621	7.814
		630	51.9	2.218	9.008

[12] This probability meets and exceeds the 1 in 100 metric set forth in the Commission's adopted, but not yet effective rules. *See Mitigation of Orbital Debris in the New Space Age*, 85 Fed. Reg. 52422, 52450-51 (Aug. 25, 2020) (to be codified at 47 C.F.R. § 25.114(d)(14)(ii)).

Although there are no failure scenarios that would prevent reentry within 25 years, Amazon also analyzed the probability of collision with small debris or meteoroids that would cause loss of control and prevent *active* post-mission disposal, as shown in Table 3.[13]

Table 3. Lifetime Probability of Collision with Small Debris or Micrometeoroids that Would Cause Loss of Control and Prevent Active Post-Mission Disposal

Shell	Altitude [km]	Inclination [deg]	Probability of Collision
1	590	33	0.00224
2	610	42	0.00281
3	630	51.9	0.00330

The lifetime small debris risk numbers shown in Table 3 are conservative, as they assume that the full surface area of critical components is exposed to the total small debris flux, regardless of the direction of the flux, orientation of the component, or shielding provided by non-critical components or structures. To help ensure Kuiper Satellites can withstand impact by small debris and remain operable, Amazon is using a combination of component design and Whipple shielding to protect all components, especially the battery and the propellant tank. Kuiper Satellites also include backup systems, such as independent solar panels and redundant flight computers, radios, and sensors to preserve the likelihood of propulsive post-mission disposal in the event of a collision.

[13] Amazon calculated this probability using NASA's Orbital Debris Engineering Model ("ORDEM") version 3.1, the same tool used by DAS version 3.1.1. The probability is the accumulated risk over the operational lifetime of the satellite.

Accidental Explosions[14]

As with debris release, Amazon has also assessed and limited the probability of accidental explosions during and after completion of mission operations as well as the probability of release of liquids that will persist in droplet form. Amazon will use Krypton as the satellite propellant and has tested the propellant tanks with Whipple shields to demonstrate that most penetrating impacts will not cause rupture at pressures at or below expected operating pressure. The Krypton propellant itself is an inert noble gas, which significantly reduces the risk of accidental explosions and prevents droplet coalescence that could otherwise contribute to orbital debris generation. In addition, each Kuiper Satellite's propellant tank is designed to leak rather than burst in most shield-penetrating impact scenarios involving small micrometeoroid orbital debris. Amazon tested the tanks' failure characteristics under hyper-velocity impact to verify this result. The Kuiper Satellite battery system also includes Whipple shields to help ensure that penetrating impacts do not result in punctures of individual cells. In the rare event of a cell puncture, battery cells are electrically isolated from neighboring cells via fuses, and the pack is designed and tested to meet passive propagation resistance to ensure a single cell entering thermal runaway does not propagate across the battery.

As discussed in more detail below, Kuiper Satellites will reserve Krypton on board to reduce perigee altitude to 350 km at the end of mission life. The Kuiper Satellites will then use

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[14] 47 C.F.R. § 25.114(d)(ii) (requiring "[a] statement that the space station operator has assessed and limited the probability of accidental explosions during and after completion of mission operations. This statement must include a demonstration that debris generation will not result from the conversion of energy sources on board the spacecraft into energy that fragments the spacecraft. Energy sources include chemical, pressure, and kinetic energy. This demonstration should address whether stored energy will be removed at the spacecraft's end of life, by depleting residual fuel and leaving all fuel line valves open, venting any pressurized system, leaving all batteries in a permanent discharge state, and removing any remaining source of stored energy, or through other equivalent procedures specifically disclosed in the application").

the remaining propellant to further reduce apogee, continue collision avoidance maneuvers, and finally vent any residual propellant,[15] leaving all lines open, followed by reentry and rapid demise. These measures demonstrate that Amazon has limited the probability of debris generation resulting from conversion of energy sources on board the satellite into energy that fragments the satellite.

Collision Risks with Large Objects[16]

As required by the Commission's rules, Amazon has similarly assessed and limited the probability that a Kuiper Satellite will become a source of debris by collisions with large debris or other operational space stations. To begin with, Kuiper Satellites will be equipped with an onboard propulsion system and will typically remediate collision risks larger than 1 in 100,000 throughout mission life—a risk mitigation threshold ten times more stringent than common industry practice.[17] Amazon will use this system for active avoidance of other spacecraft and tracked inert objects, including during deorbiting and at the post-mission disposal stage.

[15] As noted, Kuiper Satellites use Krypton, an inert propellant, rather than a reactive fuel.

[16] 47 C.F.R. § 25.114(d)(14)(iii) (requiring "[a] statement that the space station operator has assessed and limited the probability of the space station becoming a source of debris by collisions with large debris or other operational space stations. Where a space station will be launched into a low-Earth orbit that is identical, or very similar, to an orbit used by other space stations, the statement must include an analysis of the potential risk of collision and a description of what measures the space station operator plans to take to avoid in-orbit collisions. If the space station operator is relying on coordination with another system, the statement must indicate what steps have been taken to contact, and ascertain the likelihood of successful coordination of physical operations with, the other system. The statement must disclose the accuracy - if any - with which orbital parameters of non-geostationary satellite orbit space stations will be maintained, including apogee, perigee, inclination, and the right ascension of the ascending node(s). In the event that a system is not able to maintain orbital tolerances, *i.e.*, it lacks a propulsion system for orbital maintenance, that fact should be included in the debris mitigation disclosure. Such systems must also indicate the anticipated evolution over time of the orbit of the proposed satellite or satellites.").

[17] *See* NASA, *NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook* at 33-34 (2020), https://nodis3.gsfc.nasa.gov/OCE_docs/OCE_50.pdf.

In addition to active mitigation measures, Amazon's comprehensive space debris avoidance program will also include an effective, timely response to data messages from the 18th Space Control Squadron and/or other debris tracking services that advise of collision risk, as well as "full lifecycle" collision avoidance, from early operations after dispensing, to reentry. These active mitigation measures are designed to reduce the risk of collision between an operational Kuiper Satellite and a large object to near zero.

Amazon has assessed and limited the probability of collision between a non-maneuverable Kuiper Satellite and other large objects (10 cm or larger in diameter) during the total orbital lifetime of each Kuiper Satellite, including any deorbit phases, to less than 0.001 (1 in 1,000). Amazon's DAS analysis results are shown in Table 4.[18]

Table 4. Analysis of Non-Maneuverable Kuiper Satellite Lifetime Probability of Collision with Large Objects (10 cm or Larger in Diameter)

Shell	**Altitude [km]**	**Inclination [deg]**	**Probability of Collision**
1	590	33	0.0004899
2	610	42	0.0006263
3	630	51.9	0.0007212

Kuiper Satellites in each shell will use an orbit with a reference altitude and inclination as outlined above in Table 1. During ongoing operations, the ability of Kuiper Satellites to maintain strict operating altitudes also promotes safety. The Kuiper Satellites will deploy and maintain apogee and perigee to within 7 km of their nominal operational altitude. The natural motion imposed by Earth's oblateness, plus orbital eccentricity mean and variance—in combination with

[18] This probability satisfies the 0.001 metric set forth in the Commission's adopted, but not yet effective, rules. *See* 85 Fed. Reg. at 52450-51 (to be codified at 47 C.F.R. § 25.114(d)(iv)(A)(1)).

the satellites' ability to maneuver—result in no more than 9 km of cumulative altitude deviation. The right ascension of the ascending node of the satellites' orbit will exhibit secular precession and thus is not constrained to any specific value throughout the mission. The satellite orbit inclination will be subject to natural perturbations due to lunar-solar gravity but will stay within 0.1 degree of the operational inclination throughout the mission. Kuiper Satellites will maintain their respective orbits to a drag-free trajectory through propulsion and navigation systems. Orbital altitude will be held constant throughout mission life, with expected deorbit trajectory at the end of mission life, consistent with the plot shown in Figure A, below.

Based on a review of the existing space surveillance network ("SSN") catalog, Kuiper has identified no space stations with orbits "identical, or very similar, to" the Kuiper Satellites that would create additional risk and require coordination.[19] Amazon has reviewed the SSN catalog and determined that no active spacecraft have identical altitude and inclinations as Kuiper orbits. For the purpose of considering "very similar" orbits, Amazon analyzed space stations within 2 degrees inclination and 10 km in altitude, which is an orbital area larger than the Kuiper Satellites' expected deviation. Currently, 30 satellites are located within two degrees of the Kuiper inclinations (33, 42, and 51.9 degrees) and within 10 km of the Kuiper shell altitudes (590 km, 610 km, and 630 km) but none create additional risk and require coordination.[20] Amazon will continue

[19] *See* 47 C.F.R. § 25.114(d)(14)(iii).

[20] Alongside the analysis of current spacecraft in similar orbits, Amazon also took into consideration both licensed systems that have yet to become operational and systems with pending license applications with the Commission. This forward-looking analysis yielded no planned systems within the aforementioned altitude and inclination range. With respect to the upper altitude limits for SpaceX's Starlink operations, the Commission required SpaceX to maintain its orbital tolerance such that its satellites fly below 580 km at all times, thereby avoiding overlap with the Kuiper System. *See In re Space Exploration Holdings, LLC, Request for Modification of the Authorization for the SpaceX NGSO Satellite System*, Order and Authorization and Order on Reconsideration, 36 FCC Rcd 7995, 8033 ¶ 66 (2021).

to monitor active spacecraft in the Kuiper orbit regions, will coordinate as necessary, and will take the risk mitigation maneuvers described below.[21]

Kuiper Satellites will utilize onboard propulsion to enable station-keeping maneuvers that will maintain the reference orbit altitude. They will conduct both orbit adjust maneuvers that change orbit station during deorbit to lower altitudes and risk mitigation maneuvers to avoid collisions with other orbiting objects. The propulsion system can deliver sufficient change in orbit velocity (delta-v) such that collision risk can typically be reduced by an order-and-a-half in magnitude, as recommended by NASA, to 3.0E-7 or lower at each conjunction event.[22] A Kuiper Satellite risk mitigation maneuver is projected to typically impart a 140 meter change in altitude and a change in alongtrack position of over 650 meters after each successive orbit revolution when compared to a no-maneuver trajectory. This maneuverability provides ample capability over the mission lifetime to avoid collisions with other objects and helps ensure mission disposal of less than 1 year using propulsion.

Upon receipt of a space situational awareness conjunction warning (a Conjunction Data Message or "CDM") from the 18th Space Control Squadron, Amazon certifies that it will review the data and take all possible steps to assess and mitigate the collision risk if necessary. Amazon will:

- Utilize all available sources of space situational awareness data for the secondary object, either from the SSN, commercial data providers, or the owner/operator of the

[21] This approach is further consistent with Condition 63 of the *Kuiper System Authorization*. *Kuiper System Authorization*, 35 FCC Rcd at 8345 ¶ 63 ("IT IS FURTHER ORDERED that Kuiper must coordinate physical operations of spacecraft with any operator using similar orbits, for the purpose of eliminating collision risk and minimizing operational impacts. The orbital parameters specified in this grant are subject to change based on such coordination.").

[22] *See* Comments of NASA, National Telecommunications and Information Administration at 11, IB Docket No. 18-313 (Nov. 10, 2020).

secondary object, if available, and assess the probability of collision associated with the conjunction.

- Calculate the probability of collision associated with the conjunction using secondary owner/operator data supplied to the 18th Space Control Squadron's Space-Track data portal, if available.
- Monitor and trend subsequent CDMs of the same conjunction to assess collision risk.
- Assess the risk posed using probability of collision, based on available data sources. If the probability of collision exceeds the Amazon risk threshold for collisions (1 in 100,000), Amazon will begin planning and screening for a risk mitigation maneuver ("RMM"). RMM data will then be provided to Space-Track for use by spaceflight operators and associated users of space situational awareness data to assist in maintaining track custody of the Kuiper Satellite. When a secondary object is a satellite, Amazon will provide the owner/operator of that satellite with the RMM information.
- Upon determining that a maneuver is necessary, Amazon will attempt to contact the operator of the second satellite directly to coordinate response and will modify satellite operations, potentially including trajectory by propulsive maneuver, as necessary.

Amazon will also share ephemeris data and other appropriate operational information with spaceflight operators via portals such as Space-Track.[23] Traditional methods of communication include email and voice call, but, for future efforts, Amazon is advancing machine-to-machine

[23] In accordance with Condition 62 of the *Kuiper System Authorization*, Amazon will "comply with the sharing of ephemeris data procedures described in section 25.146 of the Commission's rules." *Kuiper System Authorization*, 35 FCC Rcd at 8345 ¶ 62. Specifically, Amazon will "ensure that ephemeris data for its constellation is available to all operators of authorized, in-orbit, co-frequency satellite systems in a manner that is mutually acceptable." *See* 47 C.F.R. § 25.146(e).

communication interface protocols to help scale these communications based on the constellation traffic levels expected.

All of these measures will span the phases of Kuiper Satellite operations. Kuiper launch and early operation procedures will be attentive to space debris concerns from the outset. When Kuiper Satellites separate from the launch vehicle, Amazon will take the mitigation measures discussed in this orbital debris mitigation plan.[24] After injection at or near 400 km and successful checkout, each Kuiper Satellite will initiate collision avoidance procedures that will continue throughout on-orbit operations, thus protecting previously launched space vehicles through active conjunction assessment and maneuvering as necessary. To further mitigate the risk of collision, Amazon will coordinate during operations, in real-time, with systems through whose orbital altitudes Kuiper Satellites will transit.[25]

In addition to automated data sharing, maneuver planning, and ephemeris exchange protocols, Amazon will promote and engage in manual interaction to support the flight dynamics activities of other active spacecraft. Again, each Kuiper Satellite will typically keep collision risk below 1 in 100,000 by maneuvering against all trackable debris and spacecraft, throughout all mission phases.

Amazon will track each of the Kuiper Satellites and will identify Kuiper Satellites from the ground. After orbital insertion, Kuiper Satellites will activate redundant onboard Global

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[24] As previously noted, the Kuiper satellites do not rely on mechanical release bands, breakaway mechanisms, or mechanical cutaway devices to release from the launch vehicle or to actuate deployable structures on the satellite, limiting the chance that debris will be released during normal deployment and thus minimizing collision risk.

[25] In accordance with Condition 63 of the Kuiper Grant, Amazon will "coordinate physical operations of spacecraft with any operator using similar orbits, for the purpose of eliminating collision risk and minimizing operational impacts." *Kuiper System Authorization*, 35 FCC Rcd at 8345 ¶ 63.

Navigation Satellite System ("GNSS") receivers and tracking, telemetry, and control ("TT&C") carriers to establish health and safety and navigation status. Following signal acquisition, Amazon will actively track these satellites through on-board telemetry, which will include identification and navigation data.

Each Kuiper Satellite will be registered with the 18th Space Control Squadron prior to launch. Injection orbit parameters, launch location, target date and time of launch will be provided to the 18th Space Control Squadron prior to launch to aid in detection, tracking, and custody of Kuiper Satellites by the U.S. Space Command Space Surveillance Network. Amazon's active tracking technique will produce updated satellite predictive ephemerides for the 18th Space Control Squadron to assist with United States Space Command catalog updates and custody of the Kuiper Satellites and for owner and operator distribution. In the unlikely event that any Kuiper Satellite becomes incapable of maintaining its orbital positioning, a "Non-Maneuverable" status for that satellite will be reported to 18th Space Control Squadron via Space-Track, which is available for registered satellite owners and operators, like Amazon.

As part of its space safety plans throughout these phases, Amazon has discussed its mission operations plans with government entities. For example, Amazon has discussed its conjunction assessment and risk mitigation techniques with the 18th Space Control Squadron, the NASA Conjunction Assessment and Risk Analysis program, and NASA TOPO to establish planning coordination with NASA spaceflight operations. In accordance with NASA TOPO recommendations, with respect to inhabitable spacecraft, Kuiper Satellites will adhere to NASA's ISS collision screening keep-out envelope restrictions, which are +/- 2 km radial, +/- 25 km local horizontal. In addition to maneuvering, Kuiper Satellite activities will include deorbit timing selection to de-conflict planar conjunctions from inhabitable spacecraft. Amazon has entered into a Space Situational Awareness information sharing agreement with U.S. Space Command.

Kuiper Satellites will not engage in planned proximity operations.

Post-Mission Disposal[26]

Kuiper Satellites will further avoid creating orbital debris by actively de-commissioning and deorbiting through atmospheric reentry within one year after the active mission lifetime, which is expected to be seven years. Amazon will not use direct retrieval. A number of safeguards will promote safety during the de-commissioning process. For example, Kuiper Satellites will continue to perform avoidance maneuvers consistent with on-going conjunction assessment plans.

Kuiper Satellites will also reserve limited amounts of inert gas propellant for post-mission disposal maneuvers and will maintain collision avoidance activities in a continued effort to ensure space safety, even after orbit lowering. Specifically, at the end of their mission life, Kuiper Satellites will retain enough propellant on board to reduce perigee altitude to 350 km. Under this scenario, Amazon analyzed the reentry time for the highest operational shell over the period of 2023-2043. If no further action were taken at this phase, a rapid, natural decay from the disposal orbit for the highest operational shell would occur in less than 1.5 years, with 85% of reentry times less than one year. The cases greater than one year occur only during the solar minimum (every 11 years) and, even in failure scenarios, are not expected to exceed 10 years. A representative reentry is shown in Figure A, illustrating the apogee and perigee altitudes using DAS.

[26] 47 C.F.R. § 25.114(d)(14)(iv) (requiring "[a] statement detailing the post-mission disposal plans for the space station at end of life, including the quantity of fuel - if any - that will be reserved for post-mission disposal maneuvers. . . . . The statement must also include a casualty risk assessment if planned post-mission disposal involves atmospheric re-entry of the space station. In general, an assessment should include an estimate as to whether portions of the spacecraft will survive re-entry and reach the surface of the Earth, as well as an estimate of the resulting probability of human casualty.").

After reducing perigee altitude to 350 km, any residual propellant will be used to lower apogee and continue collision avoidance either until exhaustion, or until the point at which apogee is less than the altitude of the International Space Station. At that juncture, Kuiper Satellites will use the remaining propellant to further reduce apogee, and finally vent any residual propellant, which will be followed by planned uncontrolled reentry and rapid demise. The Kuiper Satellites will each reserve sufficient propellant, 3.0 kg, for disposal maneuvers, capable of imparting 85 meters/second of delta-v budget for deorbit.

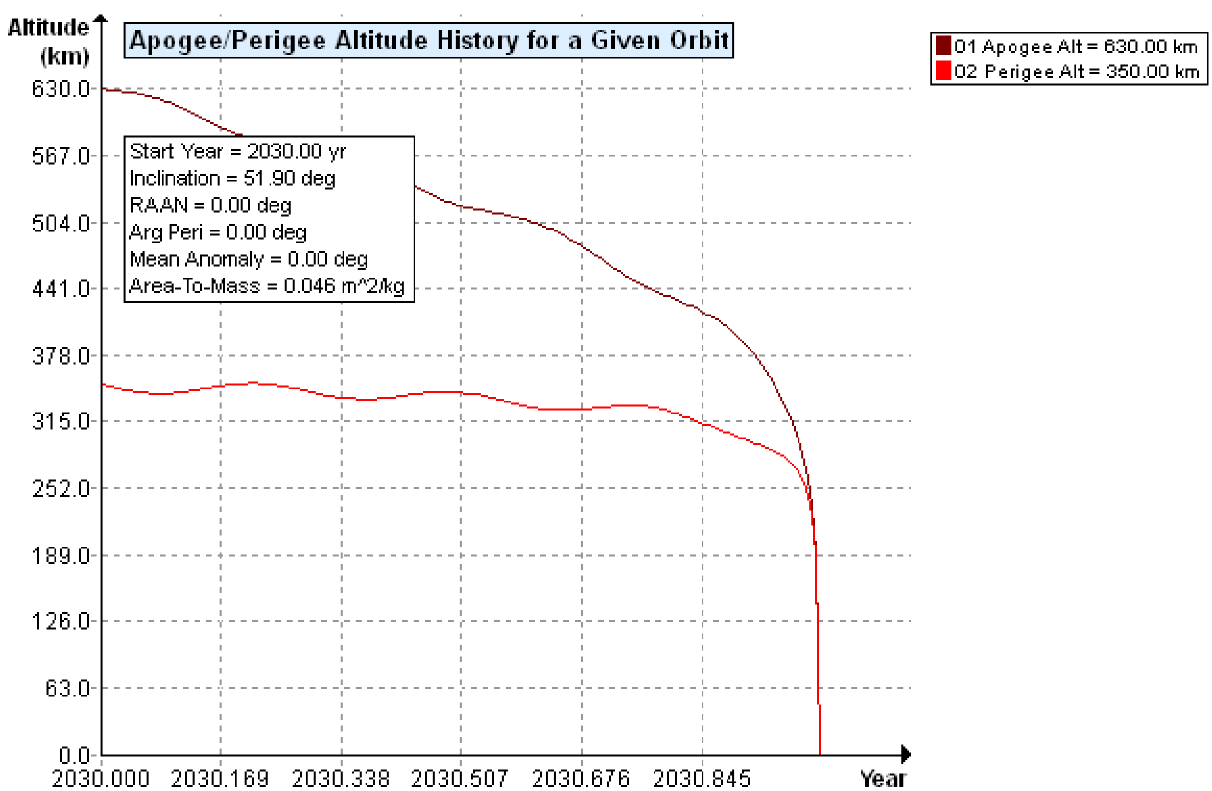

Figure A. Natural Decay from Shell 3 630 km Disposal Orbit

During these orbit-lowering maneuvers, collision avoidance will be active through publication of predictive ephemerides, ongoing screening, and adjusted burn plans to respond to identified risks above the maneuver threshold, among other things. Additionally, if at any time failures render a Kuiper Satellite unable to perform deorbit and the failure impedes ground communications, the satellite will autonomously release any stored energy. Considering the space environment at the Kuiper System altitudes, passive reentry will occur well within 25 years, as derived from the small debris risk analysis described above.[27]

Finally, Kuiper's post-mission disposal approach complies with the Orbital Debris Mitigation Standard Practices ("ODMSP") standard[28] and the NASA standard[29] of less than 1 in 10,000 risk of casualty from surviving components with impact kinetic energies greater than 15 joules. Amazon verified a less than 1 in 10,000 casualty risk for an individual satellite.[30] Amazon modeled 64 types of components per satellite, each with its own shape, material, mass, and dimensions. The components were modeled in a highly conservative nested fashion, where a child component would not be exposed to aerodynamic heating until its parent component completely demised. For each Kuiper Satellite, seven different types of components survived reentry to reach the surface of the Earth, all of which had a kinetic energy of less than 15 joules and thus did not contribute to the casualty risk. The risk of human casualty was calculated as 1 in 100,000,000, demonstrating that Kuiper exceeds the ODMSP and NASA standards.

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[27] The probability of success exceeds the adopted but not yet effective requirement of 0.9 or greater for any individual space station. *See* 85 Fed. Reg. at 52450-51 (to be codified at 47 C.F.R. § 25.114(d)(vii)(D)(1)). It also exceeds the Commission's goal for large systems of achieving a probability of success for any individual space station of 0.99 or better. *See id.*

[28] *See* U.S. Government Orbital Debris Mitigation Standards Practices, November 2019 Update, at 4-1.a, https://go.nasa.gov/3ogiMp3.

[29] *See* NASA Technical Standard, Process for Limiting Orbital Debris, NASA-STD-8719.14C, at 4.7.2.2 (Nov. 5, 2021), https://standards.nasa.gov/standard/nasa/nasa-std-871914.

[30] Amazon used DAS and the European Space Agency's higher fidelity assessment tool, Debris Risk Assessment and Mitigation Analysis ("DRAMA"), version 3.0.4, consistent with the Commission's adopted but not yet effective rule. *See* 85 Fed. Reg. at 52450-51 (to be codified at 47 C.F.R. § 25.114(d)(vii)(D)(2)(ii)).

ENGINEERING CERTIFICATION

I hereby certify that I am the technically qualified person responsible for preparation of the engineering information contained in this Application for Modification of Kuiper Systems LLC for Authority to Launch and Operate a Non-Geostationary Satellite Orbit System in Ka-band Frequencies, that I am familiar with Part 25 of the Commission's rules, that I have either prepared or reviewed the engineering information submitted in this application, and that it is complete and accurate to the best of my knowledge and belief.

/s/ Marco Concha
Marco Concha
Flight Dynamics Engineering Manager
Kuiper Systems LLC

Date: December 7, 2021