SUBMITTED ELECTRONICALLY VIA IBFS

September 18, 2019

Mr. Jose P. Albuquerque
Chief, Satellite Division - International Bureau
Federal Communications Commission
445 12th Street, S.W.
Washington, DC 20554

Re: Kuiper Systems LLC
IBFS File No. SAT-LOA-20190704-00057
Call Sign S3051

Dear Mr. Albuquerque:

We are pleased to submit this response to your August 19, 2019 letter requesting additional information concerning the above-referenced application of Kuiper Systems LLC ("Kuiper"), a wholly owned subsidiary of Amazon.com Services, Inc. (collectively "Amazon"), to launch and operate a non-geostationary satellite orbit ("NGSO") system (the "Kuiper System").[1]

Amazon has designed the Kuiper System constellation, and is maturing its satellite design and operational procedures, with space safety foremost in mind. Principal features of the Kuiper System constellation that will ensure safe space operations include: (i) altitudes at 590 km, 610 km, and 630 km chosen to permit rapid de-orbit; (ii) orbital shells with inter-shell altitude separation of 20 km and intra-shell, in-track satellite separation of at least 50 km; (iii) initial satellite injection orbit below the International Space Station ("ISS"); and (iv) comprehensive in-orbit performance verification at the injection orbit before raising satellites to their operational orbits.

The Kuiper System's satellite design and operational procedures are similarly being developed to preserve a safe space environment. Amazon is pursuing, among other things (i) a highly reliable

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[1] *See* Letter from Jose P. Albuquerque, Chief, Satellite Division, International Bureau, Federal Communications Commission, to C. Andrew Keisner, Lead Counsel, Kuiper Systems LLC (Aug. 19, 2019); *see also generally* Application of Kuiper Systems LLC for Authority to Launch and Operate a Non-Geostationary Satellite Orbit System in Ka-band Frequencies, IBFS File No. SAT-LOA-20190704-00057, Call Sign S3051 (filed July 4, 2019) (the "Application").

satellite design, consistent with the operational characteristics described in the Application that minimizes the potential for orbital debris and related risks; (ii) extensive on-ground qualification of Kuiper System satellites and sub-systems; (iii) use of conjunction avoidance maneuvering throughout all phases of satellite operations, including checkout, on-station, and de-orbiting; and (iv) development of collision avoidance and other operational procedures with internal targets above any currently applicable standards for NGSO systems. Amazon is also actively working to facilitate the advancement of space situational awareness technologies to enhance orbital debris detection and avoidance for all satellite operators.

Certain Kuiper System features and operational procedures necessarily remain subject to further development as Amazon optimizes specific elements of its satellite design. As the Commission has acknowledged in prior NGSO application proceedings, continued refinement of system design that does not alter fundamental operational characteristics of the constellation is expected in the early stages of system development and will not affect the Commission's processing of the Application.[2]

Responses to International Bureau Questions

1. *Kuiper states that satellites will be deorbited first to a perigee lower than the ISS, and then to an apogee lower than the ISS. Please provide a more precise explanation that includes the altitudes the satellites will be lowering to, as well as the number of maneuvers required for perigee and apogee lowering, the time between the proposed maneuvers, and remaining orbital life following completion of maneuvers. Please describe any plans for coordination with ISS operations.*

As an initial matter, Amazon will coordinate its satellite deorbit activities with NASA generally, and for ISS operations specifically. Amazon will conduct deorbit operations consistent with agreed parameters, including ensuring that no operational action is required by the ISS.

The specific deorbit maneuvers for a Kuiper System satellite will depend on factors such as initial orbital altitude and the varying drag effects of solar activity. Although the Kuiper System satellites would naturally deorbit within the 25-year disposal guideline contained in NASA's standard,

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[2] Commission precedent recognizes that many NGSO system applications have been accepted for filing with certain technical elements subject to finalization, and Amazon acknowledges that the Commission could condition a license grant on submission and approval of updated technical information. *See e.g.*, *WorldVu Satellites Limited Petition for a Declaratory Ruling Granting Access to the U.S. Market for the OneWeb NGSO FSS System*, Order and Declaratory Ruling, 32 FCC Rcd 5366, ¶ 24(e) (2017) (conditioning grant of OneWeb's NGSO satellite system authorization on the submission of comprehensive technical showings in the 10.7-12.2 GHz, 12.2-12.7 GHz, and 17.8-18.6 GHz bands at least 90 days prior to the initiation of service to the public); *see also Application of Space Exploration Holdings, LLC for Approval for Orbital Deployment and Operating Authority for the SpaceX NGSO Satellite System*, Memorandum Opinion, Order, and Authorization, 33 FCC Rcd 3391, ¶¶ 15, 41(p) (2018) (conditioning grant of SpaceX's NGSO satellite system authorization on submission and Commission approval of updated orbital debris mitigation information).

Amazon is taking a proactive approach to safely deorbit the satellites in a fraction of that time. In addition to implementing conjunction avoidance maneuvering throughout the satellite's operational lifetime, Amazon will reserve sufficient fuel to conduct a powered deorbit and conjunction avoidance maneuvering during the deorbit process as described below.[3]

To facilitate conjunction avoidance, efficient deorbit operations, and rapid satellite demise, Amazon will deorbit satellites using a powered, elliptical orbit lowering process, which includes:

- Perigee Lowering: To initiate deorbit, we will lower the perigee of the satellite's orbit to 350 km by conducting 30-minute burns every orbit (centered on apogee) and expending approximately 80 m/s ΔV. The target perigee will be achieved within 95-130 days.[4] The change in trajectory from these 30-minute burns is slow and predictable (perigee is lowered approximately 2.1 km per day), and the satellite's perigee will not reach the ISS's 400 km altitude until approximately 90-110 days of perigee lowering have elapsed.

- Apogee Lowering: The additional drag associated with perigee lowering will reduce the apogee over time. While apogee lowering primarily results from the combined effects of perigee lowering and drag, Amazon will use any additional propellant beyond that required for conjunction avoidance to accelerate apogee lowering below that of the ISS. This, in turn, will reduce deorbit periods below those conservatively calculated based solely on perigee-lowering. The apogee of a deorbiting satellite will be below the ISS's altitude for approximately the last 10% of the satellite's total deorbit period. Amazon will perform conjunction avoidance maneuvers throughout apogee lowering.

- Re-entry and Demise: Assuming conservatively that no propellant is available for apogee lowering beyond that required for continued conjunction avoidance, the number of days between the end of perigee lowering and re-entry can vary considerably based on initial orbital altitude and solar activity. The average period can be as short as 40 days during periods of high solar activity (resulting in a minimum deorbit period of approximately 135 days) and as long as 225 days during periods of low solar activity (resulting in a maximum deorbit period of approximately 355 days).

The use of a powered, elliptical deorbit trajectory enhances space safety for a number reasons, including (i) reduction in deorbit time and even greater reduction in the probability of conjunctions or collisions because more time is spent at lower altitudes with lower debris density; (ii) disparate orbital characteristics that minimize the potential for conjunctions with objects in circular orbits, such as the ISS; and (iii) simplified avoidance maneuvering, when required to address potential

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[3] The values stated herein concerning perigee lowering, apogee lowering, re-entry, and demise are averages across the Kuiper System unless otherwise indicated.

[4] Duration to achieve the target perigee depends on initial altitude and solar activity. During periods of low solar activity, Amazon may decrease the target perigee for deorbiting satellites to facilitate more rapid deorbit.

conjunctions with objects in circular orbits because potential conjunction risk is generally limited to a single, predictable pass.

Given the foregoing maneuvers process and time frames, a deorbiting Kuiper System satellite will briefly cross the ISS altitude only twice per orbit until the apogee is below 400 km. During this period, separation of orbital plane and anomaly[5] reduces the potential for conjunctions and facilitates any required deconfliction in a single pass. Initial deorbit right ascensions of the ascending node ("RAAN") will be selected to use differential precession to minimize orbital alignment and potential conjunctions during descent.

Although the potential need for maneuvering during the deorbit period is small, Kuiper System satellites will maneuver as needed to avoid conjunctions throughout the deorbit process until just prior to re-entry when controlled maneuvering is not possible. The propellant budget allocates ΔV sufficient to maneuver and to avoid objects using a more stringent standard than is currently required. As a result, Kuiper System satellites will be well-equipped to operate in and help maintain a safe space environment throughout their operational lifetime, including deorbit operations.

2. *Please provide a brief description of the status of system design with respect to debris mitigation. (Note that some text in the debris mitigation section suggests that design has been completed, others that it is underway but not completed).*

As discussed above, the Kuiper System's constellation design and implementation plan are well-developed, and Amazon continues to mature its satellite design and operational procedures.

The Kuiper System's orbital architecture uses inter-shell and intra-shell, in-track satellite separation distances that essentially eliminate the potential for collisions amongst Kuiper System satellites and permits satellite operations at altitudes with relatively low orbital debris density, which mitigates the risk of collision from micro-meteoroids and other debris. In addition, the Kuiper System operational altitudes enable rapid deorbit and thus further reduce any potential orbital debris impact.

The Kuiper System's satellite design is also progressing with orbital debris mitigation in mind. To the extent possible, Amazon is designing sub-systems to withstand impact from non-trackable debris without major fragmentation risk. For example, Amazon intends to use a propulsion system with a chemically inert propellant and is exploring innovative propellant solutions that can be

[5] The term "anomaly" is used in the Keplerian orbital mechanics sense. *See* NASA Reference Publication 1009, An Introduction to Orbit Dynamics and Its Application to Satellite-Based Earth Monitoring Missions, at 11 (1977), *available at* https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19780004170.pdf.

unpressurized. As another example, Amazon is designing its battery system to limit adjacent cell damage in the event of impact.

Amazon continues to refine its satellite design with respect to orbital debris mitigation and will provide updated information to the Commission consistent with the Commission's rules.

3. *Kuiper states that it will comply with NASA standards concerning surviving debris. If the design of the system is sufficiently advanced, please provide DAS (or other modeling tools) analysis that estimates the potential energy of any surviving debris, as well as the casualty risk. Please indicate what steps have been taken or will be taken to design satellites for complete demise upon re-entry. Alternatively, please provide an estimate of the aggregate casualty risk from re-entry of surviving debris for all satellites planned for launch (3,236 plus any replenishments). In providing this estimate, please estimate and use the number of satellites to be launched during the initial license term as a basis for calculation.*

Amazon is optimizing its satellite design, including specific components and materials. Although Amazon seeks to use materials and components that will demise fully upon re-entry into the Earth's atmosphere, the specific design and composition of certain satellite components remains outstanding. As a result, Amazon is not yet able to provide a DAS analysis or other meaningful estimates requested in Question 3.

Amazon understands the design and manufacturing considerations relevant to satellite demisability and will remain mindful of these considerations in finalizing its satellite design. After Amazon has finalized its satellite design, we will provide a DAS analysis to the Commission consistent with the Commission's rules.

4. *Please provide an estimate of collision risk for individual satellites that fail at the "check-out" orbit and at each of the three mission orbits. Please provide an aggregate collision risk estimate for all satellites planned for launch, assuming satellite failure rates (failures that result in loss of maneuver capability) of 5, 10, and 15 percent.*

Amazon is fully committed to implementing and operating the Kuiper System consistent with the highest standards of space safety. Amazon is also committed to partnering with others to enhance orbital debris detection and avoidance for all NGSO satellite operators, as well as to work with domestic agencies and international organizations to support the continued development and adherence to industry standards and best practices.

Amazon will include safeguards in its satellite design and manufacturing processes to minimize the potential for on-orbit satellite failure. We will conduct comprehensive on-ground qualification of Kuiper System satellites and sub-systems. Furthermore, Amazon will conduct verification testing in-orbit for every satellite before raising to its operational orbit, as well as continually monitor the health of each satellite throughout its operational lifetime. As a result, Kuiper System satellites will be designed, manufactured, qualified, and operated to specifications and tolerances that will ensure potential failure rates are well below those proposed in this question.

Nevertheless, assuming a Kuiper System satellite failure as suggested by the Commission, the lifetime probability of collision between such a satellite and any trackable 10 cm debris is still extremely remote. To analyze potential collision risk, analysis was conducted using the current baseline Kuiper System satellite design in stowed (i.e., solar panels retracted) and unstowed (i.e., solar panels extended) configurations at check-out orbit (assumed at 350 km), and in unstowed / deployed configuration at each of the three Kuiper System operational orbits (590 km, 610 km, and 630 km).

The probability of collision for a single satellite that fails at 350 km in stowed configuration is 1.1 x 10^{-7}. The probability of collision for a single satellite that fails at 350 km in unstowed configuration is 1.265 x 10^{-6}. The probability of collision for a single satellite that fails in an unstowed configuration at 590 km, 610 km, or 630 km is 0.0002084, 0.0003602, and 0.0005170, respectively.

With respect to aggregate collision risk for all satellites in the Kuiper System, Amazon again underscores that failure rate assumptions of 5%, 10%, or 15% of the fully deployed system are well beyond what Amazon would view as expected or acceptable. Nonetheless, Amazon provides the following per-shell probabilities of collision at the failure rates assumed by the Commission. The aggregate probability of collision for the 590 km shell experiencing satellite failures of 5%, 10%, or 15% would be 0.0081685, 0.0163369, and 0.0245055, respectively. The aggregate probability of collision for the 610 km shell experiencing satellite failures of 5%, 10%, or 15% would be 0.02333965, 0.0466793, and 0.07001895, respectively. The aggregate probability of collision for the 630 km shell experiencing satellite failures of 5%, 10%, or 15% would be 0.0298849, 0.0597698, and 0.0896547, respectively. The aggregate probability of collision for the entire Kuiper System constellation experiencing satellite failures of 5%, 10%, or 15% evenly distributed across the three orbital altitudes would be the sum of the collision probability for each shell associated with the assumed failure rate.[6]

5. *Please provide a more complete explanation of what happens if a satellite loses communications with ground stations for an extended period of time. For example, if a satellite is out of communication with ground stations, what is the potential for the satellite to automatically enter an end-of-life configuration and become a possible source of uncontrolled debris?*

Amazon's stringent design, manufacturing, qualification, testing, and operational safeguards, as well as inherent redundancy in Kuiper Satellite control systems, make extended loss of satellite communications very unlikely. Nonetheless, Amazon is developing operational procedures and satellite functionalities designed to maximize space safety and mitigate the orbital debris impact of any satellite that loses communications with its ground stations. One such process is to

[6] To the extent the Commission compares such aggregate probabilities of collision against probabilities previously provided by other NGSO applicants, it is worth noting that some NGSO applicants were asked to assume different aggregate failure rates. Amazon also notes that the above probabilities likely overestimate the collision risk for satellite failures of 5%, 10% or 15% across the Kuiper System constellation since, even assuming failure rates as proposed in Question 4, most failures would likely occur at the check-out orbit where the probability of collision is lower.

commence automated powered deorbit procedures if a satellite has lost communications with the Kuiper System ground network control for an extended period of time.

The powered deorbit process employs an elliptical orbit with widely disparate characteristics from objects in circular orbits and results in reduced deorbit time, greatly reducing potential for conjunctions.

Amazon will constantly and vigilantly monitor all of its Kuiper System satellites on orbit. If a satellite loses communication with the ground network, Amazon would estimate when the satellite will initiate automated deorbit procedures, confirm the initiation of such procedures through monitoring and tracking, perform conjunction analysis, and share such information with relevant operators. The rate of change in trajectory of any deorbiting Kuiper System satellite would be slow, affording Amazon and any other potentially affected operators time to fully analyze and avoid any predicted conjunction risk.

A satellite undergoing automated deorbit also would undergo automated passivation after expending its fuel. This passivation process involves de-energizing all energy reservoirs (*i.e.*, propellant tanks, battery cells, and momentum storage devices) and leaving all fuel lines open. Charging circuits will also switch off or fuse to preclude any potential recharge. Passivating a satellite in automated deorbit mode further reduces the orbital debris risk posed by the satellite.

Amazon continues to refine its automated deorbit and passivation procedures and anticipates additional internal and industry consideration of this approach to enhancing space safety. Amazon will provide updated information to the Commission consistent with the Commission's rules.

6. *When a satellite is launched and positioned below the ISS so that the operation of nominal systems can be validated, what happens if a failure is detected in a satellite? Are there different responses based on the level of failure severity? If so, please include information regarding the levels of severity and responses.*

Amazon has not yet fully assessed and characterized the potential severity and impact of all conceivable failure modes that could affect a Kuiper System satellite. However, potential irregularities can be divided into two broad categories: (i) those which do not affect safe operations but instead may affect other satellite functions (*e.g.*, minor variances in communications antenna performance, battery charge, etc.); and (ii) those which may affect safe operations, such as irregularities affecting conjunction avoidance maneuvering or powered deorbit operations.

With respect to irregularities that do not materially affect safe flight operations, Amazon will evaluate the potential impact on a case-by-case basis. For example, to the extent an irregularity would result in shorter in-orbit lifetime or sub-nominal performance, Amazon will assess the operational impact of deploying or not deploying the satellite. With respect to irregularities that may materially affect safe flight operations, Amazon will take aggressive measures to resolve the issue and, if an adequate resolution cannot be achieved, it will deorbit the satellite.

Regardless of the circumstances, Amazon will respond to any potential irregularity with space safety as the highest priority. Amazon will provide the Commission with additional information regarding the Kuiper System's concept of operations, including responses to potential irregularities, consistent with the Commission's rules.

7. *Please provide additional detail concerning the propulsion system. Specifically, please indicate the propellant composition, and the passivation procedures, including addressing the use of an unpressurized system and the efficacy of leaving fuel lines in such a system open.*

Several candidate propulsion systems remain under consideration, ranging from conventional designs using pressurized noble gas propellant to designs using liquid ionic propellant that can be non-pressurized. Amazon is conducting testing and analysis necessary to finalize the design of its satellite propulsion system. All candidate propellants are non-flammable and will sublime into space as gases under ordinary temperature profiles. Amazon will provide updated information on its propulsion system design and propellant composition consistent with the Commission's rules.

8. *Please provide fuel quantities for post-mission disposal purposes.*

As mentioned in the previous response, Amazon has not yet selected its final propulsion system design. Accordingly, Amazon has calculated maneuvering requirements in ΔV terms rather than fuel quantities because the various propulsion systems under consideration each require different fuel budgets and residuals.

Propellant budgets vary by orbital altitude for each of the three Kuiper System shells due to effects of the solar cycle, station-keeping, avoidance maneuvers, and deorbit requirements. Amazon will develop final fuel budgets to permit orbit-raising and conjunction avoidance maneuvering throughout the satellite's operational lifetime and deorbit process described herein. As with its propulsion system design and propellant composition, Amazon will provide updated information on its fuel budgets consistent with the Commission's rules.

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Amazon looks forward to engaging with the Commission and interested parties regarding these and other issues associated with space safety and operation of the Kuiper System.

Sincerely,

/s/ C. Andrew Keisner
C. Andrew Keisner
Lead Counsel
Kuiper Systems LLC,
an Amazon subsidiary