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November 19, 2018

Ms. Marlene H. Dortch, Secretary
Federal Communications Commission
445 12th Street, S.W.
Washington, D.C. 20554

Re: Unlawful Failure of Oversight of Commercial Space Operations
IB Docket No. 18-313

The Federal Communications Commission ("FCC") has for years entirely abdicated its responsibility to protect human health and the environment from atmospheric pollution from commercial space activities. Public Employees for Environmental Responsibility ("PEER") has obtained information which indicates that a key component manufacturer supplying the operators of vast satellite communications mega-constellations with ion propulsion systems, used to elevate the satellite constellations to their final orbits, has designed their systems to be fueled by mercury, a highly toxic chemical that poses a worldwide threat to human health and the environment. As the FCC has already recognized:

> In the coming years, zombie and active satellites alike will have many more neighbors. One company alone plans to launch more than 10,000 satellites that will be smaller and fly closer together than previous generations. The new space race poses some tough questions. And they touch on everything from law, to policy, to engineering. Who should control space? What are the rules? And how do we ensure that satellites vital to communications, jobs, and security are launched and disposed of safely and economically?[1]

As the number of satellites in NGSO increases astronomically, so too does the risk posed by potentially toxic substances included in their construction. The potential release of mercury into the upper atmosphere by the firing of mercury-fueled thrusters could almost double the total atmospheric mercury emissions the U.S. is currently responsible for and jeopardize our international commitments as well as long-standing U.S. policy objectives of reducing mercury emissions. The FCC's current permissive regulatory approach of hands-off oversight which declines to examine the nature of the objects it authorizes to be fired into space has left a massive blind spot which should be corrected before the mega-constellations are launched and the mercury pollutants cannot be safely recovered. At a bare minimum, FCC should require a review of the technical specifications of the satellites which are being launched, their environmental impacts, consider reasonable alternatives, and determine on the record, beyond the regulated parties' self-certification, what potential environmental harms may accrue by authorizing these constellations. Because FCC has just announced a review of its rules regarding

[1] Statement of Commissioner Brendan Carr, *Re: Mitigation of Orbital Debris in the New Space Age, IB Docket No. 18-313; Mitigation of Orbital Debris, IB Docket No. 02-54 (Terminated)*, FCC 18-159, DOC-355099A4.pdf (Nov. 15, 2018).

space debris, this is a key moment for the FCC to ensure that spacecraft design protects both the orbital and terrestrial environments.[2]

ENVIRONMENTAL IMPACTS OF MERCURY IN SPACE

Mercury is a highly toxic heavy metal that poses a global threat to human health and the environment. Together with its various compounds, it has a range of severe health impacts, including damage to the central nervous system, thyroid, kidneys, lungs, immune system, eyes, gums and skin. Victims may suffer memory loss or language impairment, and the damage to the brain cannot be reversed. There is no known safe exposure level for elemental mercury in humans, and effects can be seen even at very low levels.

Once released, mercury persists in the environment where it circulates between air, water, sediments, soil and biota in various forms. Mercury can be transported long distances in the atmosphere. It can also be incorporated by microorganisms and converted to methylmercury, and then concentrated up the food chain. Despite these dire threats to human health and the environment, mercury is used in a variety of industrial processes due to its unique elemental properties. In addition to its well-known uses in gold mining and industrial processes that produce chlorine and sodium hydroxide (mercury chlor-alkali plants) or vinyl chloride monomer for polyvinyl chloride (PVC) production, mercury is an excellent fuel source for electric propulsion systems mounted on satellites for several reasons:

[2] *See FCC Fact Sheet: Mitigation of Orbital Debris in the New Space Age*, FCC-CIRC1811-02, https://docs.fcc.gov/public/attachments/DOC-354773A1.pdf.

a. because it is a liquid at low temperatures, the propellant tankage does not need to be heated significantly to maintain the propellant in liquid form;
b. because of its high density, it can be stored in a small volume;
c. because it is a liquid, it can be stored in a lightweight, low-pressure tank; and
d. because of the high cost of launching satellites, minimizing these two metrics, volume and mass, is critical to spacecraft system design.

For these reasons, mercury was used as an early test-propellant on several experimental satellites in the early space age. The Space Electric Rocket Test ("SERT") 1 and 2 satellites launched by NASA in 1964 and 1970 and the Engineering Test Satellite (ETS)-3 launched by the National Space Development Agency of Japan in 1982 proved the effectiveness of mercury as a propellant. Despite early successes, the technology ultimately fell out of favor due to, *inter alia*, environmental concerns and risks of contamination to ground-side technicians. A report in 2005 noted that because of these concerns, use of mercury in gridded-ion thrusters had completely ceased. See Alex Kieckhafer & Lyon B. King, *Energetics of Propellant Options for High-Power Hall Thrusters*, PROCEEDINGS OF THE SPACE NUCLEAR CONFERENCE 2005, PAPER 1092. Because the spaceflight industry essentially self-cleared mercury out of its inventory, current national and international regulatory frameworks largely omit spacecraft as potential sources of mercury emissions, and air quality rules only account for emissions directly into the atmosphere.

Going against the general understanding that mercury was a dead fuel, Apollo Fusion, a startup tech company based in California's Silicon Valley, found that the lack of regulatory restrictions on mercury in space made it a cheaper, more efficient fuel than anything else in the market. In developing their Apollo Constellation Engine ("ACE"),

Apollo tested several fuel types and found that if the corrosive effects of mercury on the spacecraft could be controlled, and they could keep the use of mercury secret, the ACE could seriously outperform its competitors indefinitely. To date, no other electric propulsion thruster can match the efficiency or power of the ACE, and leading experts in the plasma and fusion fields are convinced that Apollo has made a miraculous breakthrough because they all assume that the ACE uses xenon as a fuel source. *See*, *e.g.*, Dr. Matthew Moynihan, *A Quick Analysis Of Apollo Fusion Inc.*, LINKEDIN (Apr. 5, 2017), https://www.linkedin.com/pulse/quick-analysis-apollo-fusion-inc-dr-matthew-moynihan/. The reality is far simpler: Apollo has chosen to ignore environmental externalities and write a new chapter in the global tragedy of the commons that is atmospheric mercury pollution. The ACE was tested with three different propellants: mercury, xenon, and krypton, but mercury's clear advantages made it the final decision. There is no reason, however, that other fuels could not be used, except that their price and efficiency make them less desirable.

THE APOLLO FUSION ENGINES WILL DEPOSIT UP TO 200 METRIC TONNES OF MERCURY INTO THE ATMOSPHERE

The mercury fueled Hall effect thruster designed by Apollo Fusion functions by ionizing vaporized mercury and then accelerating it out of a thruster nozzle at high speeds by carefully designed electric and magnetic fields. The mean velocity of mercury ions as they leave the thruster is 15 km/sec, within a normal distribution of +/- 1 km/sec. Multiple companies have received approval for deployment of enormous satellite networks criss-crossing the sky which dwarf the number currently in orbit. OneWeb, a

communications company deploying a network of satellites for worldwide satellite broadband internet service, has received authorization from the U.S. Federal Communications Commission for 720 satellites and is seeking authorization for nearly 1,980 in low earth orbit, and a further 2,560 in medium earth orbit of 8,500 km.[3] The low-earth orbit constellation alone has been described by the United Nations General Assembly Committee on the Peaceful Uses of Outer Space as among the first "megaconstellations" in orbit.[4] SpaceX has been granted approval for deployment of almost 12,000 satellites in multiple orbital planes as low as 340-550 km in altitude, which will require more frequent and more powerful thruster use to maintain orbit, while Kepler Communications, Inc., Telesat Canada, and LeoSat MA, Inc., got approval for various services, though with 140, 117 and 78 satellites proposed respectively, they aren't nearly as ambitious in scale.[5] As of January 1, 2018, there were only 1,459 satellites *total* in orbit, marking this as a bellwether moment for the future of the regulation of space as the number of satellites in orbit is prepared to skyrocket.

If a corporation such as SpaceX, OneWeb, or another major space company were to deploy an entire proposed LEO constellation with cheaper and more powerful mercury-fueled thrusters on-board, they could be launching as much as 198 tonnes of mercury into orbit, which will then be fired off into the upper atmosphere. Assuming the satellites are designed for a ten-year lifetime, approximately 20 tonnes of mercury would

[3] IBFS File No. SAT-AMD-20180104-00004

[4] See *Thematic priority 3. Enhanced information exchange on space objects and events: Note by the Secretariat*, A/AC.105/1170 ¶ 38, n. 13 (Nov. 15, 2017), V.12-08095(E) 051217 061217.

[5] IBFS File Nos. SAT-LOA-20170301-00027, SAT-PDR-20161115-00114, SAT-PDR-20170301- 00023, SAT-PDR-20161115-00112

be released per year, with the majority emitted for the initial orbital raising to a hypothetical 1,200 km altitude, and the remainder used for plane changes, station-keeping, and de-orbiting at the end of their operational lifetime. To place this number in perspective, the United Nations Environment Programme's draft Global Mercury Assessment for 2018 estimates that the U.S. and Canada combined emitted only 40 tonnes of Mercury into the air in 2015.

While the mercury emitted by the satellites would be into the ionosphere and exosphere, even the emissions at the full altitude of 1,200 km will slowly mix down over a period of approximately 1-3 years by molecular diffusion to the top of the mesosphere where turbulent mixing will bring it near the surface in a matter of months due to its high molecular mass. At the proposed 1,200km altitude, satellites orbit at a velocity of about 7km/s. If the Hg ions leave the satellite in the opposite direction at 15km/s, with respect to the Earth the ions are moving at about 8km/s. This velocity is lower than the escape velocity from Earth's gravitational well at that altitude (about 10km/s), so the mercury simply does not have enough energy to escape, and thus stays in Earth's atmosphere. The mercury ions quickly interact/collide with other particles in the ionosphere, losing most of their energy and turning into neutralized atoms. Gravitation causes the high molecular mass mercury atoms to diffuse earthwards through the ionosphere until they reach the turbopause at about 80-100km altitude. From this altitude, turbulent mixing incorporates the mercury into the stratosphere. In the stratosphere, the mercury is rapidly oxidized and bound to particulate, which is then removed into the troposphere. At this point, the

satellite-originated mercury is indistinguishable from the mercury emitted from other sources.

THE EMISSION OF MERCURY INTO THE ATMOSPHERE IS IN VIOLATION OF MULTIPLE INTERNATIONAL AND NATIONAL LAWS

Mercury emissions are regulated by numerous national statutes and international agreements due to its highly toxic nature. The launch of satellite constellations is governed by the laws of the United States and any nation from whose territory the launch commences, such as France, the UK, or Kazakhstan. Internationally, terrestrial mercury emissions are partly controlled by the Minamata Convention on Mercury, however its specific use and waste-disposal restrictions do not cover emissions from space.

Article 3 of the Minamata Convention restricts the use of primary-mined, imported, or exported mercury to the production of enumerated mercury-added products, specified manufacturing processes, or permanent disposal. It is not currently known where Apollo Fusion is sourcing its supply of mercury for use as thruster fuel, but if the satellite thrusters are fueled prior to their transport abroad, formal notice must be given by the United States to the launching nation, which must then decide whether to accept the import of mercury under Article 3. FCC approval of this kind of deployment launch without guarantees that these inevitable regulatory snafus abroad can be resolved is pointless.

Non-Enforcement by the United States Federal Communications Commission is in Violation of U.S. Law.

Under U.S. law, the Federal Aviation Administration Office of Commercial Space (AST) is empowered to promulgate regulations consistent with public health and safety

as requirements for issuing a license for a US person to launch a payload into space from inside or outside the US. 51 U.S.C. § 50905. The FAA, under this authority, requires information to be provided for payload review, including identification of all hazardous materials. 14 C.F.R. § 415.59(a)(6). Payloads subject to regulation by the FCC, however, are exempt from this review. 14 C.F.R. § 415.53.

The FCC review process of applications for satellite space station authorizations on form FCC 312 asks only a single question about environmental impacts, limited to the definition in 47 C.F.R. § 1.1307, which considers *only* "human exposure to [hazardous] levels of radiofrequency radiation" or high intensity lighting. No other environmental impacts, including mercury emissions or the presence of other hazardous materials in launch payload, are currently reviewed by the FCC, and regulated parties are welcome to self-certify compliance with even that lax requirement. This regulatory gap is in plain noncompliance with national commitments to eliminate potential avenues for mercury emissions. The FCC process is also not in compliance with the National Environmental Policy Act, 42 U.S.C. § 4321 *et seq.*, which requires that a federal agency contemplating a major action prepare, at minimum, an environmental assessment. FCC's NEPA regulations unlawfully and categorically exclude entire swaths of their activities under 47 C.F.R. § 1.1306, which should be immediately rewritten.

The FCC explicitly abdicated responsibility for reviewing design packages or construction contracts which might have disclosed the presence of 198,000 kg of mercury being intentionally shot into the atmosphere in a 2015 order titled *Comprehensive Review of Licensing and Operating Rules for Satellite Services*, IB Docket No. 12-267, Second Report

and Order, FCC 15-167 (2015), which eliminated "any need for submission of confidential contract or design materials to the Commission to prove that the milestones have been completed." Under this legal interpretation, commercial space companies could launch nuclear weapons into space and the FCC would still call it legal.

In October 2017 testimony before the Senate Committee on Commerce, Science, and Transportation, the founder of one large satellite communications company, OneWeb, decried the regulatory gap that currently exists for environmental management of outer space and insisted that it was an opportunity for the United States to "take a leadership position and drive standards of excellence and stewardship worldwide." While that statement was made in the context of orbital debris, his focus on preventing environmental damage through "thoughtful, common-sense rules" should encompass all the materials used for satellite construction, including toxic fuels.

Finally, the export of pre-fueled thrusters to an international launch facility is in violation of the Mercury Export Ban Act of 2008, which prohibits, under the Toxic Substances Control Act, "the export of elemental mercury from the United States." 15 U.S.C. § 2611(c)(1).

CONCLUSION

For these reasons, the FCC should immediately act to correct this glaring regulatory myopia in management and oversight of the construction of spacecraft as well as current orders granting authorization to deploy constellations. The OneWeb megaconstellation is the first of its kind in Non-Geostationary Satellite Orbit, and other companies have plans to deploy even larger networks of communications satellites

potentially using similar means. Just one of the several proposed megaconstellations would *quadruple* the number of active satellites and present the risk of a monumental environmental catastrophe if they are deployed with mercury-fueled thrusters. It is critical that the world stop this easily preventable environmental catastrophe before it begins.

Respectfully Submitted,

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