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Where No One Can Hear You Scream: Regulating the Commercial Space Industry to Ensure Human Safety

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WHERE NO ONE CAN HEAR YOU SCREAM: REGULATING THE COMMERCIAL SPACE INDUSTRY TO ENSURE HUMAN SAFETY

Outstanding Note of the Year (2019)

Kurt Harris†

CONTENTS

CONTENTS 375
INTRODUCTION 376
I. THE PERILS OF SPACE 380
  A. *Microgravity* 380
    1. Musculoskeletal Deterioration 380
    2. Cardiovascular Maladaptation 383
  B. *Radiation* 384
  C. *Biology* 388
    1. Dysbiosis & Immune System Dysregulation 388
    2. Increased Virulence of Pathogens 389
  D. *Continuing Research* 390
II. REGULATION OF U.S. INDUSTRIES 392
  A. *Current Status of US Space Regulations* 393
  B. *Commercial Aviation* 394
  C. *Mining* 395
  D. *Nuclear Power* 396
III. PRACTICAL APPLICATIONS TO SPACE 398
  A. *Governing Agency* 400
  B. *Authority* 402
  C. *Safety Education* 403

† J.D. Candidate, 2020, Case Western Reserve University School of Law; B.A. Kennesaw State University; I dedicate this Note to my wife, Laura, whose long-suffering and understanding through this odyssey of law has made all of my successes herein possible. And to my daughters, Aurora and Arcadia, who constantly test my knowledge of outer space with questions and demands for stories. I would like to thank Professor Sharona Hoffman and Andrew Condiles for their excellent feedback in the process of writing this Note, and the rest of the Health Matrix office for all of their hard work. Finally, I would like to thank Tom Walden, for long ago inspiring in me a passion for space.

D. *Separate Regulatory Schemes Dependent of Level of Danger* 403
E. *Duty of Care* 404
CONCLUSION 404

INTRODUCTION

On July 20, 1969, at 10:56pm EDT, Neil Armstrong stepped off the platform of the Eagle landing module onto the surface of the Moon.[1] Millions of people on Earth watched that step, united in a mix of breathless anticipation, stunned silence, and shouts of joy as Armstrong uttered his immortal phrase, “one small step for man, one giant leap for mankind.”[2] There is, perhaps, no other moment in history that so perfectly captures humanity’s collective desire to understand our universe, to explore, to push back the darkness that surrounds us.

After celebrating the fiftieth anniversary of that monumental step, America finally seems ready to take the next one; this time with superstar billionaires stealing the limelight from the likes of NASA and Armstrong. Sir Richard Branson plans to personally fly into space as Virgin Galactic’s first commercial passenger by 2020.[3] Everyone’s favorite billionaire entrepreneur, Elon Musk, set 2024 as the year when his interstellar venture, SpaceX, will send the first humans to Mars, laying the groundwork for a “thriving city and eventually a self-sustaining civilization.”[4] The founder of Amazon and wealthiest person in modern history,[5] Jeff

1. *July 20, 1969: One Giant Leap for Mankind*, NASA, https://www.nasa.gov/mission_pages/apollo/apollo11.html [https://perma.cc/KS7M-SWU4] (last updated July 15, 2019).

2. *Id.*

3. Soo Youn, *Richard Branson’s Virgin Galactic Plans Tourist Trips to Space Within a Year*, ABC NEWS (July 9, 2019, 1:08 PM), https://abcnews.go.com/International/richard-bransons-virgin-galactic-plans-tourist-trips-space/story?id=64215747 [https://perma.cc/GE4W- NQKB].

4. *Missions to Mars*, SPACEX, https://www.spacex.com/mars [https://perma.cc/QR5G-Y5N8] (last visited Dec. 18, 2018).

5. Robert Frank, *Jeff Bezos is Now the Richest Man in Modern History*, CNBC (July 16, 2018, 2:55 PM), https://www.cnbc.com/2018/07/16/jeff-bezos-is-now-the-richest-man-in-modern-history.html [https://perma.cc/U4AW-LTDA].

Bezos, envisions a future with a trillion humans populating the solar system, and he founded Blue Origin to help achieve that vision.[6] The way these titans of industry speak about space, it can seem as though the only thing holding humanity back from the stars is a little chutzpah and technical ingenuity. However, the many challenges that remain unsolved prove that the road to becoming a multiplanetary civilization will not be so simple.

Humanity has in many ways tamed its terrestrial home, but outer space provides unique challenges not found on Earth. Those challenges truly make space a frontier, not just in the physical sense, but in a legal one as well. Indeed, even some of the most basic legal questions concerning space remain unresolved today, more than half a century since man first entered space.[7] Now, research into the effects of space on human biology has uncovered a host of dangers that humanity faces there.[8] Safeguarding human health from these perils will require a meaningful legal framework to guide the space industry, and the U.S. doesn't have another half-century to build it.

While corporations continue to leap forward in their efforts to make human access to space cheaper and easier,[9] legislators have failed to keep pace.[10] Regulations safeguarding the health

6. Sara Salinas, *Jeff Bezos Predicts We'll Have 1 Trillion Humans in the Solar System, and Blue Origin Wants to Help Get Us There*, CNBC (Oct. 15, 2018, 3:10 PM), https://www.cnbc.com/2018/10/15/blue-origins-jeff-bezos-predicts-1-trillion-humans-in-the-solar-system-wired-summit.html [https://perma.cc/H2X7-D6PK].

7. One of the bigger debates in the law of space right now is the question of exactly where the line is separating Earth's atmosphere from outer space. As there is no physical barrier or the like demarcating the boundary, solving this legal question would simply require enough people agreeing on a single definition of where to put that line. *See* Katherine M. Gorove, *Delimitation of Outer Space and the Aerospace Object – Where Is the Law?*, 28 J. SPACE L. 11, 11 (2000).

8. *See* JAY C. BUCKEY, JR., SPACE PHYSIOLOGY (2006).

9. *See* Dana Hull, *Musk's SpaceX Doubles Down on Method for Cheaper Rocket Launches*, BLOOMBERG (Dec. 12, 2017), https://www.bloomberg.com/news/articles/2017-12-12/musk-s-spacex-doubles-down-on-method-for-cheaper-rocket-launches [https://perma.cc/KC4K-VKFK].

10. Loren Grush, *House Bill Would Regulate Bold Commercial Space Missions – But Not Very Closely*, VERGE (Apr. 24, 2018, 11:51AM), https://www.theverge.com/2018/4/24/17272338/hr-2809-

and safety of commercial space travelers or defining the extent of corporate liability are sparse.[11] Such lack of clarity risks deterring widespread corporate engagement with the commercial space industry. Many businesses may hesitate to invest if their returns are uncertain.[12] For those that invest in space despite the uncertainty, there are few controls beyond personal morals to ensure that human safety takes priority over a healthy profit.[13]

American and Russian scientists have studied the impact of microgravity[14] on astronaut's and cosmonaut's[15] skeletal structures, bone and muscle mass, cardiovascular and immune systems since the first manned missions beyond Earth's atmosphere.[16] The few humans who temporarily left the protection of Earth's magnetosphere[17] risked the additional

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american-space-commerce-free-enterprise-act-regulation [https://perma.cc/2DXR-5X7J].

11. *C.f.* 14 C.F.R. §§ 414, 417, & 460 (2006).

12. AEROSPACE INDUSTRIES ASSOCIATION, RESTRUCTURING COMMERCIAL SPACE REGULATION 2 (Mar. 1, 2018), https://www.aia-aerospace.org/report/restructuring-commercial-space-regulation/ [https://perma.cc/6QGD-F676] [hereinafter AIA REGULATION].

13. *C.f.* 14 C.F.R. §§ 414, 417, & 460 (2006).

14. *See* Raul Herranz et al., *Ground-Based Facilities for Simulation of Microgravity*, 13 ASTROBIOLOGY 1, 2 (2013) (describing microgravity as when the effects felt as a result of gravity are significantly less than what is felt on the surface of the Earth).

15. Robert Frost, *What Are the Differences Between an Astronaut and a Cosmonaut?*, FORBES (May 11, 2017, 3:21 PM), https://www.forbes.com/sites/quora/2017/05/11/what-are-the-differences-between-an-astronaut-and-a-cosmonaut/#3ed27bb3fa7c [https://perma.cc/ FN5N-CM54] (defining cosmonaut as the Soviet (now Russian) equivalent of American astronauts).

16. Dave Dooling, *Space Travel Increases Some Health Risks*, NASA SCIENCE (Nov. 4, 1998), https://science.nasa.gov/science-news/science-at-nasa/1998/msad04nov98_1 [https://perma.cc/N4M3-M7BY].

17. Magnetosphere refers to a magnetic field that surrounds a planet. *Magnetospheres*, NASA SCIENCE, https://science.nasa.gov/heliophysics/focus-areas/magnetosphere-ionosphere [https://perma.cc/P382-73QP] (last visited Feb. 5, 2019). Earth's magnetosphere is generated by the rotation and metallic composition of its core and does much to protect humans on the surface from. *Id.*

dangers of solar and cosmic radiation, potentially more damaging to the human body than all but the worst man-made radiation humans are likely to experience here on Earth.[18] The astronauts NASA chooses to face such risks must satisfy a list of exacting qualifications combining education, experience, and physical health requirements.[19] The average citizen is comparatively unprepared, and as normal people begin leaving their earthly home for life in space, in greater numbers than any NASA mission, the need to address these environmental hazards will only become more pronounced.

If the United States wishes to remain the preeminent space-faring nation on Earth,[20] it must develop a robust regulatory framework that will nurture the bourgeoning commercial space industry while safeguarding the health and safety of crew and passengers. Failure to do so increases the risks both of tragedy in space and the subsequent slow-down or collapse of the commercial space market as the public loses faith in the space industry.

Section I of this Note examines the expected health hazards that humans will face based on current research and the experiences of astronauts, cosmonauts and the crew of the International Space Station. Section II discusses the current state of U.S. regulations regarding human health and safety in space as compared with other major and/or hazardous industries. Although specific regulatory recommendations are beyond the scope of this article, Section III examines the potential lessons that we might learn from existing regulation of other industries to use as a framework as we build the legal foundations for our next steps in space.

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18. *5 Hazards of Human Space Flight*, NASA, https://www.nasa.gov/feature/5-hazards-of-human-spaceflight [https://perma.cc/V5L6-3UYA] (last updated Mar. 8, 2019); Angela Kinoshita et al., *Electron Spin Resonance (ESR) Dose Measurement in Bone of Hiroshima A-Bomb Victim*, PLoS ONE 1, 6 (2018).

19. *Astronaut Requirements*, NASA (June 21, 2017), https://www.nasa.gov/audience/forstudents/postsecondary/features/F_Astronaut_Requirements.html [https://perma.cc/5MXH-QQ7N].

20. BRYCE SPACE AND TECHNOLOGY, GLOBAL SPACE INDUSTRY DYNAMICS 1, 3–4, 8–9 (2017), available at https://brycetech.com/downloads/Global_Space_Industry_Dynamics_2017.pdf [https://perma.cc/528T-L62D].

I. THE PERILS OF SPACE

A. Microgravity

The idea that there is no gravity in space is a popular myth.[21] Rather, a planet's gravity exerts its pull more strongly the closer you are to its center of mass, and more weakly the further you get from that center.[22] For example, astronauts roughly 250 miles up aboard the International Space Station ("ISS") experience approximately ninety percent of the gravity that we experience on Earth's surface.[23] Thus, astronauts do not float because of a lack of gravity, but rather because they, and the entire ISS itself, are being pulled back toward the Earth like a skydiver after jumping out of the plane.[24] The ISS and the astronauts aboard only avoid a fiery reentry and violent landing back on Earth by traveling forwards quickly enough to match the curvature of the Earth as they fall, placing them in a perpetual state of freefall known as microgravity.[25] Microgravity is the first hazard of long-term exposure to space.

1. Musculoskeletal Deterioration

Perhaps the most critical hazard to human health in space is the degradation of muscle tissue and the demineralization of bone mass.[26] Human bones and muscles grow stronger when they are worked, and atrophy when they are not.[27] The Earth pulls terrestrial life toward its center of mass with an amount of force

21. Rich Schuler, *If There Is No Gravity in Space, Why Do "Shooting Stars" Fall?*, SCIENTIFIC AM., https://www.scientificamerican.com/article/if-there-is-no-gravity-in/ [https://perma.cc/HFZ6-JZPZ] (last visited Jan. 4, 2019).

22. *Id.*

23. *Id.*

24. *Id.*

25. *Id.*

26. Harry K. Charles Jr. et al., *AMPDXA for Precision Bone Loss Measurements on Earth and in Space*, 25 JOHNS HOPKINS A.P.L. TECHNICAL DIG. 187 (2004).

27. Cosimo Roberto Russo, *The Effects of Exercise on Bone. Basic Concepts and Implications for the Prevention of Fractures*, 6 CLINICAL CASES IN MINERAL & BONE METABOLISM 223 (2009); Sue C. Bodine, *Disuse-induced Muscle Wasting*, 45 INT'L J. BIOCHEMISTRY & CELL BIOLOGY 2201 (2013).

defined as one unit of gravity, or 1G.[28] The ground provides something to push against, keeping us from simply falling into the center of the Earth.[29] Our bodies, in turn, exert their own force against the ground, resisting the pull of gravity and allowing us to stand, walk, and move at will.[30] In this way, each of us undergoes a kind of weight training through mere existence, ensuring a minimum level of bodily strength.[31]

In space, however, our bodies are unable to resist gravity by pushing against the ground, so that base level of constant exercise we take for granted on Earth is lost. Unsurprisingly, the lower-body muscles used most commonly for standing and balance are the hardest hit by microgravity due to their lack of use.[32] It is currently unknown what, if any, limit exists to how far human muscle strength will atrophy in microgravity conditions, but some studies have shown normally load-bearing muscles shrinking to thirty-three percent of their original size before achieving a new environmental equilibrium.[33]

Moreover, studies show that astronaut's bones weaken in space similarly to their muscles.[34] Although scientists do not yet understand all causes of decreased bone density (demineralization) in a space environment, studies show that a key factor is that same lack of normal gravitational resistance our

28. Matt Williams, *How Strong is the Force of Gravity on Earth?*, UNIVERSE TODAY (Dec. 16, 2016), https://www.universetoday.com/26775/gravity-of-the-earth/ [https://perma.cc/6FMA-BFHT].

29. Jim Lucas, *Equal & Opposite Reactions: Newton's Third Law of Motion*, LIVE SCIENCE (Sept. 26, 2017), https://www.livescience.com/46561-newton-third-law.html [https://perma.cc/AKD2-BRU4].

30. G.A. Cavagna et al., *The Role of Gravity in Human Walking: Pendular Energy Exchange, External Work and Optimal Speed*, 528 J. PHYSIOLOGY 657, 657–58 (2000).

31. *See* Tung-Wu & Chu-Fen Chang, *Biomechanics of Human Movement and its Clinical Applications*, 28 KAOHSIUNG J. OF MED. SCI. S13, S14 (2012).

32. BUCKEY, *supra* note 8, at 78–80.

33. *Id.* at 82.

34. *See, e.g.*, Millie Hughes-Fulford, *Physiological Effects of Microgravity on Osteoblast Morphology and Cell Biology*, 8 CELL BIOLOGY AND BIOTECHNOLOGY IN SPACE 129, 129 (2002).

bodies receive on Earth.[35] Bone loss caused by exposure to microgravity may vary among different people and different sections of the body.[36] Overall, however, the parts of the skeleton that bear the brunt of our weight here on Earth, such as the hips and lower spine, tend to likewise bear the brunt of demineralization in space.[37] Some studies have recorded losses of up to 1.7% total mass per month of exposure to microgravity.[38] For comparison, average bone loss attributable to the normal aging process falls into the range of 2–13% per *decade*.[39] Osteoporosis is typically diagnosed after a 30% drop in bone mass compared to typical levels as a young adult,[40] meaning a young, healthy astronaut could be diagnosed with osteoporosis after less than 18 months in the weightless environment of space. As in the case of muscle atrophy, we do not yet know how far the bone demineralization could continue in a microgravity environment, but some mathematical models suggest potentially up to a sixty percent loss of bone density.[41] Such drastic drops in muscle mass and bone density could mean months or even years of physical therapy upon returning to Earth simply to be able to walk and move normally.

Despite maintaining a nutrient-rich diet[42] and engaging in an average of two and a half hours of vigorous exercise daily[43] while in flight, astronauts returning to Earth still report significant

35. VLADIMIR PLESTER, GRAVITY, WEIGHT AND THEIR ABSENCE 79 (2018).

36. BUCKEY, *supra* note 8, at 12.

37. *Id.*

38. *Id.*

39. Ellen J. O'Flaherty, *Modeling Normal Aging Bone Loss with Consideration of Bone Loss in Osteoporosis*, 55 TOXICOLOGICAL SCI. 171, 172 (2000).

40. *Understanding Bone Density Results*, AM. BONE HEALTH, https://americanbonehealth.org/about-bone-density/understanding-the-bone-density-t-score-and-z-score/ [https://perma.cc/DVD2-H85L] (last visited Jan. 10, 2019).

41. JAMES A. PENNLINE, NASA, SIMULATING BONE LOSS IN MICROGRAVITY USING MATHEMATICAL FORMULATIONS OF BONE REMODELING 1 (2009).

42. BUCKEY, *supra* note 8, at 14, 172–173.

43. *Id.* at 15.

levels of muscle and bone loss that may take months, or even years, to build back up through post-flight rehabilitation, if they can be reversed at all.[44] For normal space travelers who don't meet the current standards for NASA astronauts or match their in-flight routines, long-term exposure to microgravity will likely prove far more devastating.

2. Cardiovascular Maladaptation

Much of our modern plumbing infrastructure on Earth relies on gravity to function.[45] Similarly, the human body's "plumbing" system likewise evolved to function in 1G conditions and struggles to function normally when removed from its natural gravitational environment.[46] This was evidenced in experiments performed by the former U.S.S.R., collecting data on the hemodynamic[47] functions of twenty-six cosmonauts over more than twenty years[48]: before, during, and after spaceflights.[49] This study focused on orthostatic[50] stability through LBNP tests,[51] as well as measuring "blood flows in the aorta, medial cerebral artery, and femoral artery . . . ultrasonographically,"[52] and included the mission which set the record for continuous human habitation in a microgravity environment.[53]

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44. *Id.* at 14.

45. For example, without the assistance of gravity, communities across the US would find themselves with little to no water pressure in their homes as their local water towers would cease to function. *See How Water Towers Work,* PRACTICAL ENGINEERING, https://practical.engineering/blog/2019/3/9/how-water-towers-work [https://perma.cc/5NCZ-VFLT] (last visited Sept. 22, 2019).

46. *See* PLESTER, *supra* note 35, at 72.

47. *Haemodynamic*, OXFORD'S DICTIONARY OF ENGLISH (3d ed. 2010).

48. A.R. Kotovskaya & G.A. Fomina, *Characteristics and Maladaption of Human Cardiovascular System Under Space Flight Conditions*, 36 HUM. PHYSIOLOGY 190 (2010).

49. *Id.*

50. *Orthostatic*, MERRIAM-WEBSTER DICTIONARY (online ed.), https://www.merriam-webster.com/dictionary/orthostatic [https://perma.cc/CQ7G-JW9F] (last visited Jan. 16, 2019) ("[O]f, relating to, or caused by an upright posture . . . ").

51. Kotovskaya & Fomina, *supra* note 48, at 193.

52. *Id.*

53. *Id.*

The study found only minor effects on blood flow during the shorter trips to space.[54] However, hypovolemia (decrease in blood flow) became more pronounced the longer the mission's duration and, thus, exposure to microgravity.[55] Although blood flow continually and rapidly returned to pre-flight levels after returning to Earth,[56] cosmonauts attested to speech difficulties and sluggish thoughts during flight.[57] Of greater concern, the maladaptation of the cardiovascular system after long-term exposure to microgravity significantly increased the cosmonaut's bodily stresses during reentry, including deterioration of vision, blackouts, and disturbances in heart rhythm.[58] The effects of these changes in the cardiovascular system are thus most pronounced in already highly dangerous situations where alertness and quick thinking are most critical.[59]

Microgravity thus poses a myriad of health issues to humans in space. For short excursions above the atmosphere, such perils may be small and the risks acceptable. However, the danger grows with the amount of time spent in space. The prospect of returning to the normal gravity of Earth after any extended habitation in space may prove catastrophic, both to the people who suffer bodily atrophy from microgravity-exposure, as well as to the public faith and enthusiasm for the space industry itself. The law must protect against these perils by carefully regulating the operations of commercial endeavors in space and ensuring compliance with minimum health and safety standards while there.

B. Radiation

Radiation rivals microgravity as potentially the most dangerous environmental hazard humans face in space. There are two types of radiation, namely radiation composed of photons and radiation composed of particles.[60] Photonic radiation, also known

54. *Id.* at 191.

55. *Id.*

56. *Id.*

57. *Id.* at 192.

58. *Id.* at 194; BUCKEY, *supra* note 8, at 162.

59. *See* Kotovskaya & Fomina, *supra* note 48, at 194.

60. *Nature of Radiation*, NDT RESOURCE CTR., https://www.nde-ed.org/

as electromagnetic ("EM") radiation, is what humans most commonly interact with here on Earth.[61] It comprises a spectrum of radiation from the beneficial (radio-waves and visible light), to the harmful (gamma rays), and everything in-between (ultraviolet light and microwaves, among others).[62] Essentially, the shorter its wavelength, is the more energy the radiation carries, and the more energetic the radiation is, the more damage it can cause.[63]

Particle radiation refers to the nuclei (microscopic cores of atoms) of elements from the periodic table that have been stripped of the electrons which stabilized them (ionization), then accelerated to great speeds.[64] The danger to humans from these ionized nuclei is similar to the danger of traffic accidents on Earth; the larger the vehicle and the faster it is traveling, the more damage it will do to whatever it hits.

When the ionized nucleus of an atom interacts with a living organism, the ion loses a portion of its energy, which then gets absorbed by the biological matter.[65] If the ion transfers enough energy, it can cause the atoms of the living creature to themselves ionize, tearing apart the creature's DNA in clusters of breaks that the body cannot easily repair.[66] In controlled settings, like a laboratory or medical center, particle irradiation may be used as a treatment to destroy cancer cells.[67] In an uncontrolled environment like space, however, such collisions may shatter

EducationResources/CommunityCollege/RadiationSafety/theory/ nature.htm [https://perma.cc/K9KY-X5Q7] (last visited Jan. 10, 2019) [hereinafter *Nature of Radiation*].

61. *Id.*; *see also* LYNDON B. JOHNSON SPACE CENTER, NASA, UNDERSTANDING SPACE RADIATION 1 (2002) (applying the definition of electromagnetic radiation).

62. *Nature of Radiation*, *supra* note 60.

63. *Id.*

64. *See Why Space Radiation Matters*, NASA, https://www.nasa.gov/ analogs/nsrl/why-space-radiation-matters [https://perma.cc/ D4BD-FDUS] (last updated Jun. 11, 2018) [hereinafter *Space Radiation*].

65. LYNDON B. JOHNSON SPACE CENTER, *supra* note 61.

66. *Id.*

67. Rodrigo Fernandez-Gonzalo et al., *Impact of Particle Irradiation on the Immune System: From the Clinic to Mars*, 8 FRONTIERS IN IMMUNOLOGY 1,1 (2017).

otherwise healthy DNA, potentially damaging the cardiovascular and central nervous systems[68] and causing cancerous mutations.[69]

Interplanetary space is riddled with heavy ionized particles accelerated to near the speed of light,[70] simultaneously making them both highly dangerous and impossible to shield against with current technology.[71] Moreover, such ionized particles can not only pierce traditional radiation-shielding materials like lead, but also collide with those materials with such violence that it introduces the dangers of secondary radiation as well.[72]

Secondary radiation occurs when ionized particles collide with or move through stable matter, like that making up the spaceship, transferring a portion of their energy to the spaceship as they move past.[73] That energy transfer causes atoms in the spaceship to destabilize and transform into high-speed ions themselves,

68. Stephen Ornes, *En Route to Mars, Astronauts May Face Big Health Risks*, SCI. NEWS FOR STUDS. (Mar. 8, 2018), https://www.sciencenewsforstudents.org/article/en-route-mars-astronauts-may-face-big-health-risks [https://perma.cc/4XRQ-K4RN].

69. *Radiation*, NATIONAL CANCER INST. (Apr. 29, 2015), https://www.cancer.gov/about-cancer/causes-prevention/risk/radiation [https://perma.cc/4GZY-NC6X]; Ethel S. Gilbert, *Ionizing Radiation and Cancer Risks: What Have We Learned from Epidemiology?*, 85 INT'L J. RADIATION BIOLOGY 467, 470 (2009) (explaining the danger of cancerous mutations grows with the amount of time spent exposed to ionizing radiation, as has been shown in studies of the survivors of the nuclear bombs dropped in World War II and the subsequent inhabitants of Hiroshima and Nagasaki, Japan); Jason Daley, *Explorers Will Face Dangerous Amounts of Radiation on their Trip to Mars*, SMITHSONIAN MAG. (Sept. 24, 2018), https://www.smithsonianmag.com/smart-news/explorers-will-face-dangerous-amounts-radiation-their-trip-mars-180970384/ [https://perma.cc/L8DX-SPGS] (noting that recent studies estimate that a single round-trip to mars, not including any time spent on the surface, would expose space travelers to 60% of the maximum radiation dosage that NASA allows its astronauts to experience across their entire careers).

70. LYNDON B. JOHNSON SPACE CENTER, *supra* note 61.

71. *Space Radiation*, *supra* note 64; *Types of Radiation in Space*, NASA, https://www.nasa.gov/sites/default/files/np-2014-03-001-jsc-orion_radiation_handout.pdf [https://perma.cc/CN93-NVMK] (last visited Jan. 11, 2019).

72. FRANCIS A. CUCINOTTA ET AL., SPACE RADIATION CANCER RISK PROJECTIONS AND UNCERTAINTIES – 2012 7 (2013).

73. LYNDON B. JOHNSON SPACE CENTER, *supra* note 61, at 1.

escalating the potential damage.[74] Thus the hull and components of the ship, and even the bodies of the astronauts themselves, may be turned against them as a kind of radioactive shrapnel when subjected to cosmic radiation.[75]

On the ground, we are largely protected by Earth's strong magnetosphere, a magnetic field surrounding our planet that deflects much of the harmful cosmic radiation, and by our thick atmosphere that takes the brunt of the radioactive impact.[76] Unfortunately, our near-term prospects for new homes among the stars — namely the Moon and Mars — would offer little to no protection to occupants from either atmospheres or magnetospheres.[77] Out in the remainder of the solar system, few, if any, otherwise habitable celestial bodies have such protection from radiation as we naturally enjoy on Earth.[78] Thus, future interplanetary explorers will not only face damaging, potentially deadly levels of radiation on their journeys across space, but will continue to endure constant bombardment wherever they choose to settle.

As with microgravity, radiation in space poses significant health risks to humans and that risk grows with the amount of time spent exposed to the environment. Until technology advances to the point that it obviates such concerns, the law must stand as a safeguard of human life against unscrupulous, reckless, and negligent actions of commercial actors in space.

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74. *Id.*

75. *See generally id.*; *Space Radiation*, *supra* note 64.

76. *Space Radiation*, *supra* note 64.

77. ROBERT H. LEWIS, HUMAN SAFETY IN THE LUNAR ENVIRONMENT, NAT'L AERONAUTICS & SPACE ADMIN., SP-509, 272 (1992); *Real Martians: How to Protect Astronauts from Space Radiation on Mars*, NASA, https://www.nasa.gov/feature/goddard/real-martians-how-to-protect-astronauts-from-space-radiation-on-mars [https://perma.cc/H4LG-Q28Y] (last updated Aug. 7, 2017).

78. *The Magnetic Fiends of Our Solar System*, APEX MAGNETS (May 29, 2015), https://www.apexmagnets.com/news-how-tos/the-magnetic-fields-of-our-solar-system/ [https://perma.cc/NC5E-LMBH]; Lou Mayo, *What's Up? Magnetic Moons?*, NASA, https://sunearthday.nasa.gov/2010/getinvolved/aa_wu_magneticmoons.php [https://perma.cc/3VZV-X3TV] (last visited Jan. 11, 2019).

C. Biology

The harmful effects of microgravity and cosmic radiation on the human body are not limited to direct consequences. Together, they also harmfully alter the natural functions of our bodies.[79]

1. Dysbiosis & Immune System Dysregulation

The human immune system relies heavily on the help of symbiotic bacteria, so much so that gastrointestinal bacteria alone may be collectively thought of as a 'virtual organ,' fundamental to maintaining our health and wellbeing.[80] Our bodies, particularly the gut, contain thriving microbiomes where "healthy and pathogenic bacteria compete for dominance."[81] When helpful bacteria is able to offset the growth of the harmful bacteria, we have a normal and healthy balance that forms an essential component of our bodies' ability to fight off certain diseases.[82] Stress and activities that alter a person's normal lifestyle may also alter this balance, leading to dominance of the pathogens and, thus, disease.[83] Perpetual freefall and constant bombardment by ionizing cosmic radiation is beyond the normal routine for any average human, providing just such an environment where pathogens may thrive.

Studies performed during spaceflights of varying durations have shown impaired human immune responses not found in Earth-based control groups.[84] These studies of astronauts found a substantial number of beneficial cell types to be depressed during

79. Fernandez-Gonzalo et al., *supra* note 67, at 2; Jorge L. Cervantes & Bo-Young Hong, *Dysbiosis and Immune Dysregulation in Outer Space*, 35 INT'L REV. IMMUNOLOGY 67, 67–69 (2016); Richard B. Setlow, *The Hazards of Space Travel*, 4 EMBO REP. 1013 (2003).

80. Amir Ata Saei & Abolfazl Barzegari, *The Microbiome: The Forgotten Organ of the Astronaut's Body – Probiotics Beyond Terrestrial Limits*, 7 FUTURE MICROBIOLOGY 1037 (2012).

81. Cervantes & Hong, *supra* note 79, at 69.

82. *Id.*; *Good vs. Bad Germs*, HEALTHLINE, https://www.healthline.com/health/cold-flu/good-bad-germs#1 [https://perma.cc/9GKQ-EYVZ] (last visited Sept. 29, 2019).

83. *See* Saei & Barzegari, *supra* note 80, at 1038; Cervantes & Hong, *supra* note 79, at 69.

84. Cervantes & Hong, *supra* note 79, at 69–70.

flight, suggesting exposure to microgravity as the likely cause.[85] The astronauts aboard each spaceflight showed at least some signs of immune impairment and the effects of microgravity on the human microbiome were more pronounced the longer the exposure lasted.[86] We do not yet know the full extent of these problems with the human immune system in space, nor their lasting effects upon return to Earth and normal gravity.[87]

There is also far less information available regarding the effects of cosmic radiation on the immune system than that of a more generic space environment, mostly due to the fact that only 24 astronauts have traveled beyond the magnetic fields that help protect Earth.[88] However, *in vitro* studies of human cells have shown chromosomal damage from cosmic radiation after time in low-Earth orbit, an area outside of Earth's atmosphere, but still within its magnetosphere.[89] Any plans to colonize another celestial body would involve far greater doses of radiation due to the necessarily greater duration of exposure and intensity of bombardment beyond low-Earth orbit. As "some components of the immune system are among the most radiation-sensitive tissues in the body," radiative damage to the human immune system will likewise be a serious concern for any potential space-dweller.[90]

2. Increased Virulence of Pathogens

Although microgravity suppresses the ability of the human immune system to fight off disease, it appears to be a beneficial environment for many pathogens.[91] Studies performed during

85. *Id.* at 74; BRIAN CRUCIAN ET AL., EVIDENCE REPORT: RISK OF CREW ADVERSE HEALTH EVENT DUE TO ALTERED IMMUNE RESPONSE 8 (2015).

86. CRUCIAN ET AL., *supra* note 85, at 11.

87. *Id.* at 4.

88. Nathan Gueguinou et al., *Could Spaceflight-Associated Immune System Weakening Preclude the Expansion of Human Presence Beyond Earth's Orbit?*, 86 J. LEUKOCYTE BIOLOGY 1027, 1035 (2009).

89. Fernandez-Gonzalo et al., *supra* note 67, at 4.

90. *Id.*

91. Saei & Barzegari, *supra* note 80, at 1038; C. Mark Ott et al., *Microbial Responses to Microgravity and Other Low-Shear*

space flights showed, for instance, an increase in antibiotic resistance among various disease cultures tested, including Salmonella and *E. coli*.[92] In some cultures, this increased resistance to antibiotics appears to have fallen back to normal levels upon return to Earth and standard gravity; others, however, continued to show increased virulence once returned.[93]

Moreover, across twenty years and 106 missions with 742 crew members, studies reported twenty-nine incidents of infectious disease in flight.[94] That is twenty-nine distinct incidents, involving at least eight distinct diseases, in the most biologically isolated environment available to mankind, among highly trained astronauts in near-peak physical and medical condition, pre-screened by top medical professionals and quarantined before flight.[95] Even diseases the astronauts had already overcome prior to the quarantine and screening processes showed a resurgence with a "reactivation of latent infections."[96]

In a completely enclosed environment like a spacecraft, where air and water are constantly recirculated, even strong and robust immune systems may find themselves overwhelmed by disease. Combined with the damage and impairment that accompanies microgravity and ionizing radiation, the potential consequences to space colonizers are far more severe. These dangers pose a substantial threat to the health and safety of NASA's professional astronauts, even under the most stringent precautions. A general populace of would-be space-farers, as space visionaries like Musk and Bezos dream of, would require far more protection.

D. Continuing Research

New research like NASA's aptly named Twins Study offers at least some measure of hope. In a year-long study of biological twin astronauts, Scott and Mark Kelly, NASA observed the

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Environments, 68 MICROBIOLOGY AND MOLECULAR BIOLOGY R. 245, 246 (2004).

92. C. MARK OTT ET AL., NASA, EVIDENCE REPORT: RISK OF ADVERSE HEALTH EFFECTS DUE TO HOST-MICROORGANISM INTERACTIONS 5 (2006); Cervantes & Hong, *supra* note 79, at 71.

93. OTT ET AL., *supra* note 92.

94. CRUCIAN ET AL., *supra* note 85, at 10.

95. *Id.* at 10.

96. Cervantes & Hong, *supra* note 79, at 72.

genetic structure, intestinal microbiome, biochemical dynamics and numerous other health measurements of Scott, who lived aboard the ISS for the duration of the project, and his brother Mark, who remained on Earth.[97] Promisingly, the study showed that most of the changes to Scott's gene expression normalized shortly after landing back on Earth, and also helped to identify the genes most affected by radiation damage.[98] Scott was also able to maintain gut health and cognitive abilities for the duration of the study.[99]

However, while the Twins Study gives us valuable glimpses into the problems and potential solutions of human life in space, we cannot use it, and other studies like it, as straightforward roadmaps to follow. Even at a whole year in space, the study lasted less time than it would take to travel to Mars and back. Even aboard the ISS, Scott still enjoyed the protection of Earth's magnetosphere. Even with the unprecedented opportunity to study twins, the sample size was still just two highly trained and rigorously prepared astronauts. And despite the thoroughness of the tests, the results necessarily cannot speak to potential differences between genders, ethnicities, or ages.

The harmful effects of microgravity and radiation, whether damaging human tissue directly or indirectly by altering the balance of our symbiotic microbiota, are only a portion of the most immediate physiological problems facing humanity in space. One can't help but wonder about the potentially critical effects of prolonged isolation and confinement on human psychology, human reproduction in these environments and on other planets, and the potential problems with returning to Earth after extended exposure to the most extreme conditions in space. Continuing research and technological breakthroughs are imperative to our progress in space; however, until our understanding and technology can solve these problems, each

97. Francine E. Garrett-Bakelman et al., *The NASA Twins Study: A Multidimensional Analysis of a Year-Long Human Spaceflight*, 364 SCIENCE 1–4, 8–9, 17 (2019).

98. *Id.* at 17; *see also Twins Study Results at a Glance: What They Found and Why It's Important*, NASA, https://www.nasa.gov/sites/default/files/thumbnails/image/pinwheel_041119_me-01_0.png [https://perma.cc/H7SW-RS3Z] (last visited Aug. 16, 2019) [hereinafter *Twins Study*].

99. *Twins Study*, *supra* note 98.

presents a regulatory hurdle that needs to be addressed before reaching blindly for the stars.

II. REGULATION OF U.S. INDUSTRIES

The problems facing humanity in space are severe, if not lethal, for the unwary. At a time when multiple corporate actors have lofty ambitions to send humans to new worlds, we cannot fully grasp all of the dangers and pitfalls that we will face.[100] However, great rewards don't come without commensurate effort and risk, and there are few rewards greater than those waiting for humanity in the final frontier.[101]

Those who choose to invest in space will find a tremendous wealth of raw materials on asteroids, comets, and other celestial bodies.[102] Near-limitless energy waits to be tapped from our sun.[103] Overpopulation could be relieved through direct colonization of other planets and space-based habitats, or simply making better use of the land available on Earth by exporting large agricultural operations off-planet.[104] Apocalyptic dangers, like the proverbial doom of the dinosaurs, could be more readily detected and prevented.[105] All of this awaits humanity in space, without even mentioning the technological leaps and subsequent economic boom that would accompany space investment,[106] as the world has already enjoyed after the Cold War space-race.[107]

Those rewards will ensure that at least some countries and corporations will reach for the stars regardless of the dangers.

100. Setlow, *supra* note 79.

101. John F. Kennedy, *Address at Rice University in Houston, Texas on the Nation's Space Effort (We Choose to Go to the Moon)*, J.F.K PRES. LIBR. AND MUSEUM (Sept. 12, 1962), https://www.jfklibrary.org/asset-viewer/archives/JFKWHA/1962/JFKWHA-127-002/JFKWHA-127-002 [https://perma.cc/R282-EYHY].

102. GREG MATLOFF ET AL., HARVESTING SPACE FOR A GREENER EARTH 111 (2014).

103. *Id.* at 129.

104. *Id.* at 63–65.

105. *See id.* at 158–61.

106. INTERNATIONAL SPACE EXPLORATION COORDINATION GROUP, BENEFITS STEMMING FROM SPACE EXPLORATION 5 (2013).

107. *See id.* at 8.

International law is largely built on custom and emergent norms,[108] and the state actors blazing the trail in an area as legally undefined as outer space could hold persuasive value for other countries later attempting to develop their own laws regarding space activities. As the preeminent leader in space, the United States thus enjoys a unique position through which it may harvest the riches available in space while setting the example for those who will inevitably follow. Accordingly, it is critical that the United States proactively regulate the use of space by American corporations to protect the health and safety not only of American citizens, but of people across the globe. Fortunately, America already regulates several hazardous industries to which it may look for guidance in building a regulatory framework for commerce in space.

A. Current Status of US Space Regulations

Currently, US spaceflight is overseen by the Department of Transportation (DOT) and the Federal Aviation Administration (FAA).[109] The few regulations that we currently have deal primarily with the licensing, liability, and safety of launch from and reentry to Earth by American-based companies and entities utilizing American launch facilities.[110] The only portion of those regulations that specifically addresses the health and safety of crew and passengers is restricted to problems arising during launch and reentry.[111] The subsection relating to life support systems requires commercial operators to "provide atmospheric conditions adequate to sustain life and consciousness for all inhabited areas within a vehicle."[112] It then lists the conditions that the operators must monitor and control, such as atmosphere

108. *See generally*, Brigitte Stern, *Custom at the Heart of International Law*, 11 DUKE J. COMP. & INT'L L. 89 (2001).

109. *See generally* 14 C.F.R. Chapter III (2018); *Commercial Space Transportation*, FED. AVIATION ADMIN., https://www.faa.gov/regulations_policies/faa_regulations/commercial_space/ [https://perma.cc/G8WE-CS2B] (last updated June 1, 2018).

110. *See* 14 C.F.R. §§ 413, 415, 420, 433, 437 (2018) (regarding licensing procedures); 14 C.F.R. § 440 (2018) (regarding liability); *See* 14 C.F.R. §§ 414, 417, 431, 435 (2018) (regarding launch, reentry, and general safety requirements).

111. 14 C.F.R. § 460 (2018).

112. 14 C.F.R. § 460.11(a) (2018).

composition, pressure, temperature, ventilation, redundant supplies of breathable oxygen and the like.[113] The rules for passengers mandate that the operator must obtain the informed consent of any space flight participants before flight,[114] waivers of claims against the US government,[115] and basic emergency training reminiscent of that provided by airline flight attendants before each flight.[116] These precautions may be adequate for short, suborbital flights, but they are a long way from providing the safety mechanisms necessary for travel to and colonization of other worlds, because such voyages involve far different health risks than do launches and landings.

B. Commercial Aviation

Because of the many similarities between commercial aviation and space travel, airline regulations should provide a functional starting point for the commercial space industry. The modern U.S. regulatory regime governing commercial air travel came into being in 1958 after a mid-air collision over the Grand Canyon killed 128 people aboard two planes in the deadliest airline accident to that point.[117] The tragedy motivated the passage of the Federal Aviation Act and the birth of the regulatory agency known today as the FAA.[118]

The FAA promulgates the rules and regulations for U.S.-based airlines and travel over U.S. airspace.[119] Safety is its primary goal,[120] and it requires adherence to strict safety standards for all entities that seek to fly to, from, or within the United States.[121] For those it grants license to fly, it specifies the individuals to be held accountable for any problems that may

113. 14 C.F.R. § 460.11(a)–(c) (2018).

114. 14 C.F.R. § 460.45(f) (2018).

115. 14 C.F.R. § 460.49 (2018).

116. 14 C.F.R. § 460.51 (2018).

117. *A Brief History of the FAA*, FED. AVIATION ADMIN., https://www.faa.gov/about/history/brief_history/ [https://perma.cc/JRW9-FA8E] (last updated Jan. 4, 2017).

118. *Id.*

119. Federal Aviation Act of 1958, Pub. L. No. 85-726, 72 Stat. 731 (1958).

120. *Id.*

121. 14 C.F.R. § 5.1 (2018).

arise during flight[122] and demands continuing re-analysis of the efficacy of safety programs to identify hazards and new technology or methods that may further improve safety.[123]

Moreover, most airlines qualify as "common carriers" under U.S. law[124] and, as such, are held to "the highest degree of care"[125] in their duties toward their passengers when determining liability for negligence. Whether or not an entity is found to be in breach of its duty toward another is largely determined by the standard of care expected of it.[126] Thus, the greater the level of care ascribed to a person or corporation, the greater the likelihood of liability when something goes wrong. This 'utmost level of care,' and the added weight of liability that it carries, ensures that airlines are financially motivated to maintain their claim as being "the safest way to travel."

C. Mining

In the five-year period spanning 1906–1911, the United States mining industry suffered more than 13,000 casualties among its miners.[127] As a direct result of those tragedies, Congress established the Bureau of Mines to promote safety and stem the tide of human casualties in the mining industry.[128] Today, the regulatory regime governing the US mining industry is the Federal Mine Safety and Health Act of 1977, as amended by the MINER act of 2006 (collectively, the "Mine Safety Act"), and overseen by the Mine Safety and Health Administration

122. 14 C.F.R. §§ 5.23–.25 (2018).

123. 14 C.F.R. §§ 5.51–.75 (2018).

124. *Carrier*, BLACK'S LAW DICTIONARY (10th ed. 2014); *See* 47 U.S.C. § 153(11) (2018) (defining a common carrier as "an individual or organization . . . that contracts to transport passengers or goods for a fee.").

125. *See*, *e.g.*, Weade v. Dichmann, Wright & Pugh, Inc., 69 S.Ct. 1326, 1328 (1949).

126. *Negligence*, BLACK'S LAW DICTIONARY (11th ed. 2019).

127. *National Mine Health and Safety Academy*, MINE SAFETY AND HEALTH ADMIN., U.S. DEP'T LABOR, https://arlweb.msha.gov/PROGRAMS/EPD2.HTM [https://perma.cc/H633-Q527] (last visited Jan. 16, 2019).

128. *Id.*

(MSHA).[129] MSHA sets minimum safety standards for the use of products within mines, and the Mine Safety Act provides the steps that mine operators must follow to gain approval for such products.[130] It establishes a National Mine Health and Safety Academy,[131] joining the ranks of the more famous federal military and law enforcement schools like the U.S. Naval Academy (Annapolis), the U.S. Military Academy (West Point) and the FBI Academy.[132] It provides a central location for developing safety standards and a curriculum for training mining professionals from across the United States and the world in safe mining methods.[133]

The Mine Safety Act establishes rules for the prompt communication of hazards[134] and the training of mine rescue teams[135] and mandates minimum standards for health and safety within mines.[136] Importantly, it separates coal from other forms of mining as particularly dangerous, detailing its own, more stringent, set of health and safety regulations.[137] The statute also specifies civil penalties for violations of the act.[138]

D. Nuclear Power

As in the case of commercial-mining operations, nuclear regulation in the United States stems from violence and catastrophe. Before nuclear power was used to generate electricity, it was used to level cities.[139] The bombs used to end

129. Mine Safety and Health Admin., *Regulations*, U.S. DEP'T LABOR, https://www.msha.gov/regulations [https://perma.cc/H633-Q527] (last visited Jan. 16, 2019) [hereinafter *MSHA Regulations*].

130. 30 C.F.R. § 6.1 (2018).

131. 30 C.F.R. § 42 (2018).

132. *MSHA Regulations*, *supra* note 130.

133. *Id.*

134. 30 C.F.R. § 50 (2018).

135. 30 C.F.R. § 49 (2018).

136. 30 C.F.R. §§ 56–8, 62 (2018).

137. 30 C.F.R. §§ 70–2, 74–5, 77, 90 (2018).

138. 30 C.F.R. § 100 (2018).

139. America dropped atomic bombs on the Japanese cities of Hiroshima and Nagasaki at the end of World War II, killing hundreds of thousands between the blasts and subsequent radiation. *Atomic Bomb History*, HISTORY (Sept. 6, 2017), https://www.

World War II proved the immense destructive potential of nuclear power and the need for government regulation of its use. Even still, three subsequent disasters involving the nuclear plants at Three Mile Island, Chernobyl and Fukushima drove further regulation, and the reputational damage that these accidents caused has significantly hindered the continued growth of nuclear power adoption in the U.S.[140] While modern proponents of nuclear power tout its ability to provide abundant, steady, clean streams of electricity for public consumption,[141] detractors cite the potential for disaster and the possible threats that nuclear plants continue to pose to human life.[142] The current U.S. policy regarding nuclear power balances these two views, permitting construction and use of nuclear plants but heavily regulating their operation.

The civilian nuclear power industry in the U.S. is overseen by the United States Nuclear Regulatory Commission (NRC)[143] and governed primarily by the Atomic Energy Act of 1954 (AEA) and the Energy Restoration Act of 1974.[144] The AEA strictly regulates

history.com/topics/world-war-ii/atomic-bomb-history [https://perma.cc/DG9M-UPBC].

140. These cites suffered core meltdowns, causing actual radioactive contamination of their surrounding areas and great public concern. *Safety of Nuclear Power Reactors*, WORLD NUCLEAR ASS'N (May 2018), http://www.world-nuclear.org/information-library/safety-and-security/safety-of-plants/safety-of-nuclear-power-reactors.aspx [https://perma.cc/TRW7-MQV5].

141. *The Advantages of Nuclear Energy*, NUCLEAR ENERGY INST., https://www.nei.org/advantages [https://perma.cc/4455-ZTGA] (last visited Jan. 17, 2019).

142. *See* Chris Williams, *The Case Against Nuclear Power*, INT'L SOCIALIST REV., (May 2011), https://isreview.org/issue/77/case-against-nuclear- power [https://perma.cc/P7YS-N7NP].

143. *Organization & Functions*, U.S. NUCLEAR REG. COMM'N, https://www.nrc.gov/about-nrc/organization.html [https://perma.cc/VM5D-YHVX] (last updated July 16, 2017).

144. *Governing Legislation*, U.S. NUCLEAR REG. COMM'N, https://www.nrc.gov/about-nrc/governing-laws.html [https://perma.cc/25US-J7W5] (last updated May 21, 2018) [hereinafter *Governing Legislation*]; *see* Development and Control of Atomic Energy, 42 U.S.C. §§ 2011–2296 (2018).

nearly all aspects of the civilian nuclear power industry.[145] It prohibits production of nuclear fuel by any U.S.-based entity other than the U.S. government.[146] It authorized the Atomic Energy Commission, later replaced by the NRC, to define what constitutes nuclear fuel and source material.[147] It restricts possession, ownership, transportation and general distribution of nuclear fuel, source material and waste.[148] To those commercial actors that demonstrate that they are "equipped to observe . . . such safety standards to protect health and minimize danger to life" that the commission establishes,[149] it licenses the ability to own and use nuclear materials[150] for reactors and other "useful purpose[s]."[151]

The American industries discussed here and countless more have each seen tragedy result from their policies, mistakes, or miscalculations. Each has been forced to address the causes of those tragedies through new technology and legal minimum standards of safety. The United States must now learn from and apply the solutions found in these other industries as a prophylactic measure against further misfortune in the emerging commercial space industry.

III. Practical Applications to Space

In air travel, mining, and the utilization of nuclear power, human safety is paramount. In each case, it took mass-destruction

145. *Governing Legislation*, *supra* note 145; *see* Development and Control of Atomic Energy, 42 U.S.C. §§ 2011–2296 (2018).

146. Designated "special nuclear material" in the statute. Carveouts exist, however, for commission-approved research facilities to produce nuclear materials in small, non-weaponizable amounts. 42 U.S.C. § 2061(a) (2018).

147. 42 U.S.C. §§ 2071 & 2091 (2018) (providing that the NRC may only add to the definitions provided by congress in the AEA and later legislation).

148. 42 U.S.C. §§ 2073–75 (2018) (addressing licensure); 42 U.S.C. §§ 2093–94 (2018) (addressing distribution); 42 U.S.C. §§ 2096–99 (2018) (addressing acquisition); 42 U.S.C. §§ 2111–13 (2018) (2018) (addressing ownership).

149. 42 U.S.C. § 2133(b) (2018).

150. 42 U.S.C. § 2133(a) (2018).

151. 42 U.S.C. § 2133(b) (2018).

and human catastrophe to drive appropriate industry regulation and oversight, and in each case these industries continue to function and thrive despite that regulation. NASA has seen its own share of tragedy in the Apollo 1,[152] Challenger,[153] and Columbia[154] disasters and each time was forced to review its own safety standards and procedures. However, if America applies the lessons that it has learned from such disasters and the subsequent regulation of its other industries, it may yet avoid similar tragedies in the world of commercial space travel.

At the same time, regulations must be implemented with care, lest they protect human life by effectively prohibiting exploration of space. Too much rigidity could stifle technological innovation and corporate motivation to expand the human frontier in space;[155] too little regulation could discourage companies from investing in space for fear of liability and uncertainty.[156] Worst would be no regulation at all. Such lack of guidance would discourage most private actors from investing in space because of the uncertainty, while simultaneously incentivizing the few companies that take that risk to save on costs by cutting corners and obfuscating when something goes wrong. Even if we assume that the idyllic proclamations of current industry leaders like Bezos, Musk and Branson can be

152. The crew of the Apollo 1 died in 1967 when a spark ignited the pure oxygen atmosphere inside their command module during a launch rehearsal test. Elizabeth Howell, *Apollo 1: The Fatal Fire*, SPACE (Nov. 15, 2017), https://www.space.com/17338-apollo-1.html [https://perma.cc/WLQ7-FX7Z].

153. The Challenger space shuttle, notably crewed by Christa McAuliffe, the would-be first school-teacher in space, exploded in 1986 before leaving the atmosphere due to a faulty o-ring. Mike Wall, *Challenger Disaster 30 Years Ago Shocked the World, Changed NASA*, SPACE (Jan. 28, 2016), https://www.space.com/31760-space-shuttle-challenger-disaster-30-years.html [https://perma.cc/59QV-G7S6].

154. The Columbia and crew perished in 2003 as the shuttle broke apart during reentry attempting to return to Earth due to damage sustained during launch. Elizabeth Howell, *Columbia Disaster: What Happened, What NASA Learned*, SPACE (Nov. 14, 2017), https://www.space.com/19436-columbia-disaster.html [https://perma. cc/7538-ZTL8].

155. AIA REGULATION, *supra* note 12, at 2.

156. *Id.* at 1.

trusted, industry leadership changes, and no one can vouch for the unflagging moral fortitude of the leaders who come next.

It is, again, beyond the scope of this note to suggest specific regulations addressing the dangers of space. As scientists and engineers continually work to find technological solutions to the hazards of space, specific regulatory recommendations are likewise better left to such experts in those respective fields. The following is, rather, a proposed framework that may be used to ensure that best practices for human health are developed and followed by the government and space industry participants.

A. Governing Agency

The United States needs an administrative, regulatory agency to develop and oversee safety standards of commercial operations in outer space. This would enable administrators and subject-matter experts to make carefully-considered rules, rather than relying on congressional action, which would be undertaken by people with little understanding of the scientific basis for the laws they are passing.[157] Administrative experts would be better able to balance the risks and rewards of various rules and a regulatory agency could respond more quickly to implement new scientific understanding and technological advancements than could Congress. For these reasons, each of the industries discussed above is governed not only by legislation, but also by a regulating body specializing in that industry: airlines under the FAA, mines by the MSHA, nuclear plants by the NRC.[158] However, the nature of such a regulatory body for commercial space requires greater thought.

The commercial space industry currently falls under the jurisdiction of the DOT and the FAA.[159] While the FAA may be a viable choice to oversee Earthly launches and landings, however, its current expertise lies in short-term atmospheric flight, not long-duration space flight and operations involving

157. JENNIFER E. MANNING, CONG. RESEARCH SERV., R44762, MEMBERSHIP OF THE 115TH CONGRESS: A PROFILE 3–4 (2018) (noting only 11 of the 541 current members of congress have an occupational background in the hard sciences).

158. *See* Federal Aviation Act of 1958, Pub. L. No. 85-726, 72 Stat. 731 (1958); *MSHA Regulations*, *supra* note 133; *Organization & Functions*, *supra* note 144.

159. 30 C.F.R. §§ 400–1199 (2018); *Commercial Space Transportation*, *supra* note 109.

celestial bodies and environmental health hazards. As flights begin bringing more lay people into space for more diverse operations for longer periods of time, the FAA will find itself hard pressed to adequately address the rigors and dangers of space.

Where the FAA's expertise fails, NASA's excels. NASA's foundational focus on addressing the multitude of issues associated with space[160] make it a tempting candidate to take the reins on regulating the commercial space industry. The problem is that, unlike the FAA, NASA has little experience in regulation and administration.[161] NASA itself admits that it is "not fundamentally a public regulatory agency."[162] NASA historically has been an agency focused on science, research, and exploration, and employing NASA as the governing agency would hinder its ability to continue fulfilling its current missions. Likewise, continuing its current functions would dilute its focus on ensuring the safety of commercial passengers.

Instead of attaching the ill-fitted task of regulating the commercial space industry to an already established agency, Congress should establish a distinct new regulating entity dedicated to human safety in space. In 2002, as a response to yet another catastrophe in the September 11th attacks, Congress created the Department of Homeland Security by integrating all or portions of twenty-two federal agencies into a single, more efficient, and more capable department.[163] Similarly, Congress should integrate portions of NASA's expertise in the science and hazards of space with the FAA's and other agencies' administrative and regulatory experience to create a unified and efficient body capable of preventing and mitigating human tragedy in space.

Of course, creating any new agency will cost money, which will likely prove a point of contention for the legislative parties

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160. *Our Missions and Values*, NASA, https://www.nasa.gov/careers/our-mission-and-values [https://perma.cc/E2Q5-WNDB] (last updated May 10, 2018).

161. NASA, FINAL PLAN FOR RETROSPECTIVE ANALYSIS OF EXISTING REGULATIONS 1 (2011).

162. *Id.*

163. *Creation of the Department of Homeland Security,* DEP'T HOMELAND SEC., https://www.dhs.gov/creation-department-homeland-security [https://perma.cc/68LN-9JJE] (last updated Sept. 24, 2015).

involved. However, space holds tremendous potential as a source of economic growth,[164] and an opportunistic U.S. will only see greater evidence of this as time goes on. Failing to invest in regulation of the space industry now could easily lead to much larger expenditures after tragic loss of life in space both dampens public faith in and demand for commercial space utilization and necessitates the creation of such an agency anyway. Part of the new agency's budget would simply be reallocated from other agencies like the FAA that currently administer functions overlapping with the new agency's jurisdiction. Moreover, just as the Food and Drug Administration subsidizes a substantial portion of its operating costs with industry user fees,[165] the new agency may find similar mitigation of costs by assessing a fee to processes applications for regulatory clearance from its own industry users.

B. Authority

Just as the NRC is authorized to define what constitutes hazardous nuclear material, who may use it and how it may be used,[166] the agency set to oversee the commercial space industry must similarly have sufficient authority to set, review and update safety standards as technology and understanding of the hazards of space improve. Any lack of such authority would cripple the agency's ability to perform its function, costing taxpayers millions for little to no benefit. Similarly, lack of clarity in the limits of the authority granted to it would diminish its capacity while simultaneously increasing the costs of its bureaucracy. To effectively oversee and protect human life in space, the body regulating space safety must be clearly, specifically, and fully authorized to identify and limit the acceptable risks that civilian employees and passengers may undertake in space.

164. *See* Jeff Foust, *A Trillion-dollar Space Industry Will Require New Markets*, SPACE NEWS (July 5, 2018), https://spacenews.com/a-trillion-dollar-space-industry-will-require-new-markets/ [https://perma.cc/9T93-HCJM].

165. *See Fact Sheet: The FDA at a Glance*, FOOD DRUG ADMIN., https://www.fda.gov/about-fda/fda-basics/fact-sheet-fda-glance [https://perma.cc/735V-VGMB] (last updated Aug. 14, 2018).

166. 42 U.S.C. §§ 2071–75 (2018) (addressing the determination of nuclear material); 42 U.S.C. §§ 2091–94 (2018) (addressing licensure); 42 U.S.C. §§ 2096–99 (2018) (addressing acquisition); 42 U.S.C. §§ 2111–13 (2018) (addressing ownership).

C. Safety Education

Just as Congress created the National Mine Health and Safety Academy to help mitigate the health risks of underground operations,[167] it should likewise establish a space-health academy to mitigate the health risks in space. Such an academy would provide a place where space-health safety experts could be trained and certified for work in the industry, and where new standards could be developed and refined.[168] The hazards of space travel at least equal those of mining in their scope, and a center dedicated to the development, analysis and dissemination of safety methods would go far toward preventing otherwise avoidable catastrophe as civilians reach into space.

D. Separate Regulatory Schemes Dependent of Level of Danger

Short, suborbital flights, such as what companies like Blue Origin and Virgin Galactic are preparing to offer the paying public, may involve relatively little risk, requiring minimal regulation beyond what already exists. Longer habitation at orbital space stations or hotels within the Earth's magnetic field increase the risk of disease and other physiological problems that accompany microgravity, requiring more stringent regulations to safeguard human safety. Voyages to other celestial bodies, like Elon Musk's goal of a 2024 mission to Mars, would require even more regulation, as a voyage like this would add both the dangers of cosmic radiation and substantially greater time for the hazards of space to damage the human body. Colonization efforts will involve all the problems previously discussed, amplified by the necessarily immense amounts of time spent in these hostile environments, reaching into the realm of lifetimes and across generations. While such consequences may be temporally remote from what we can expect to deal with in the near future, we must still consider them when creating a regulatory framework meant to guide the progress of the commercial space industry.

Just as the mining regulations account for the differing levels of danger between coal and other forms of mining operations,[169] space regulations should not apply a one-size-fits-all approach to the dangers of human habitation in space. Appropriate space

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167. 30 U.S.C. § 952(c) (2018).

168. *MSHA Regulations*, *supra* note 133.

169. *See* 30 C.F.R. §§ 70–2, 74–5, 77, 90 (2019).

regulation must account for the differing levels of danger that operations in these areas imply, and address them accordingly through operational licensing or other regulatory methods.

E. Duty of Care

In tort law, the legal obligation imposed on an entity to take precautions when acting in a way that could foreseeably harm others is known as the duty of care,[170] and it is the bar by which negligence claims are measured.[171] The weight of the duty imposed varies with the likelihood of harm and the severity of the potential injury, with the greatest duty falling just short of a strict liability standard. Among those held to the highest duty of care are the modern, mass-transportation providers such as airlines, railways and city busses, all categorized as 'common carriers.'[172]

Many commercial space operations will undoubtedly fall under the umbrella of 'common carriers,' likewise requiring the highest duty of care toward their passengers.[173] Other operations like outer-space mining or construction, however, may not fit so neatly into the standard category. Nevertheless, the level of danger in space operations, and the number of unknown factors in such an unexplored area, is such that commercial enterprises in space should be subject to the utmost duty of care regardless of whether they would fit into one of the pre-defined categories already subject to it.

As with commercial airlines, such a level of negligence liability would motivate space-faring corporations to be pro-active in providing adequate precautions for the clients, passengers and employees entrusting them with their safety against the enveloping void.

CONCLUSION

The dangers inherent in leaving humanity's Earthly cradle are ones often ignored or glossed over in the popular media. Traveling in space is treated much as sailing the sea; only truly dangerous if something goes wrong with the ship. The truth, however, is that the mere existence of humans in the space

170. *Duty of Care*, BLACK'S LAW DICTIONARY (11th ed. 2019).

171. *Negligence*, BLACK'S LAW DICTIONARY (11th ed. 2019).

172. *Carrier*, BLACK'S LAW DICTIONARY (11th ed. 2019).

173. 47 U.S.C. § 153(11) (2018).

environment poses less immediate, yet still potentially lethal threats. Scientific advancement and technology may eventually alleviate some of these issues, but unless we take adequate legal measures to mitigate those threats, we risk the tragedy of Icarus as we fly too close to the sun.