How “Rad” Is a Trip to Space? A Brief Discussion of Radiation Exposure in Suborbital Space Tourism

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INTRODUCTION

On Saturday, May 30, 2020, the way we think about space travel permanently changed. Commercial space travel is now a reality. With the first ever commercial crew space launch by SpaceX’s (Hawthorne, California) Crew Dragon, private enterprise now has the ability to take humanity beyond Earth’s atmosphere. Although sending astronauts to the International Space Station from these companies is one goal (such as SpaceX’s Crew Dragon and Boeing’s [Chicago Illinois] Starliner), space tourism is another chief focus (such as Blue Origin [Kent, Washington] and Virgin Galactic [Las Cruces]). Space tourism is not new. Even in the early 2000s people were “hitching” rides to the International Space Station on Russian Soyuz launches. Those seats, however, ran about 20 to 40 million dollars and were very few. As a result of privatization and the (relatively) dramatic price reductions, we can expect a substantial increase in the number of people who will be subjected to the space environment. Even in early 2019, and at approximately $250,000 a seat, there were over 700 people on the Virgin Galactic suborbital flight waitlist [1]. The people on these lists will not always be in the physical shape of astronauts, who have strict training regimens. Therefore, it is now more important for physicians to be aware of the medical risks associated with space flight.

One might think, “That’s interesting. So what? How does this apply to a radiologist?” Space radiation is one of the more emphasized subjects in aerospace medicine, and radiologists are common subject matter experts in medical radiation physics and safety for both patients and the media. Because radiation physics, radiobiology, and radiation safety are core to radiology, understanding space radiation exposure during space flight will allow for radiologists to provide radiation-related guidance in this next stage of space travel. This could include functioning as a source of information for patients interested in such travel, as well as a source for the media when questions of health and exposure in space arise. Additionally, a basic understanding of the space radiation environment from a radiologist’s perspective could help to further research interests in radiation protection in different environments. New technological innovations from spaceflight could improve the approach to mitigating harmful exposures on Earth. Initially, the most pressing question that a radiologist might be asked, however, is the following: “As far as radiation goes, is it safe to go aboard this flight?”

SUBORBITAL SPACE FLIGHT

Radiation exposure will depend greatly on the flight plan (where the spacecraft goes and how long it is there). Currently, there are a handful of flight plans—everything from breaching the boundary to space with an airplane to flights orbiting the Earth to trips to the Moon [2,3]. Space tourism will most likely progress in a stepwise fashion from lower altitude flights on suborbital flight plans to higher altitude flight plans such as orbital and beyond low-Earth orbit flights. Each of these will carry a vastly different radiation exposure profile. Here, we primarily focus on suborbital flight plans, because this will be the initial space tourist exposure.

A suborbital flight means that a spacecraft goes straight up, breaches the “space-atmosphere” boundary, and comes right back down. The boundary of where space begins is loose; however, many define it at 100 km above sea level, which is known as the Karman line [4]. In Blue Origin’s suborbital flight plan, for example, total flight times to breach the Karman line are currently proposed to be 11 min, with only 2 min of time spent in space.

ENVIRONMENTAL RADIATION SOURCES IN THE NEAR-EARTH SPACE ENVIRONMENT

There are three main environmental sources of radiation in space flight: solar phenomena, galactic cosmic rays, and “trapped radiation” (in Earth’s case, the Van Allen belts).

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Solar phenomena describe events originating from our sun. These include the solar wind, solar flares, and coronal mass ejections and are intermittent and not completely predictable [5]. The radiation dose from these can be high, which is considered one of the largest obstacles in missions to Mars [5]. However, the Earth's magnetic field markedly reduces the radiation levels at proposed suborbital flight altitudes. To identify a worst-case scenario, data were analyzed from one of the largest solar events observed with modern equipment, the August 1972 solar event. It was estimated that the maximum dose within a spacecraft in interplanetary space during the August 1972 event was approximately 124 mSv/h [6]. This is an overestimate for proposed suborbital flights because this dose pertains to a much higher altitude with less planetary shielding. Still, even if the entire flight occurred at the higher altitude rate but included planetary shielding, the effective dose would be approximately 11.37 mSv.

Galactic cosmic rays refer to radiation from the entire universe that continually bathe the Earth in a background level of radiation. These are predominantly made of accelerated protons (87%) and helium ions (12%) [7-9]. Their energies can range from below 1 MeV per nucleon to over 1000's of GeV (giga electron volts) per nucleon [10]. However, in general, the lower the altitude, the more Earth's magnetic field protects us [11]. Using models from the Federal Aviation Administration, a peak altitude approximating the proposed Blue Origin path, over a 19-year solar cycle period (between 1994 and 2013), the highest galactic cosmic ray dose on the entire planet was 0.126 mSv/h over the northern magnetic pole [12]. Assuming all 11 min of space flight are subjected to this exposure level, the expected dose would be 0.023 mSv. Again, this value is an overestimation because suborbital flights will launch into a more shielded environment away from the magnetic poles and will not be exposed to a full 11 min at this dose rate (Fig. 1).

The trapped radiation of the Van Allen belts is the last external source of radiation in the near-Earth space environment with potential exposure to protons of energies up to 500 MeV [13]. Fortunately, it will have no impact on the current suborbital trajectories in space tourism. The lowest altitude one can come into contact with the Van Allen belts is approximately 200 km above sea level at a specific location above the Earth known as the South Atlantic anomaly [14]. This is well beyond the current flight plan's peak altitude. This radiation does have a meaningful impact on other deeper space flights including that of the International Space Station (orbiting around 400 km). As space tourism advances further beyond Earth's surface, however, exposure to Van Allen belt radiation will have to be addressed.

COMPARISON TO RADIATION DOSES WITH MEDICAL IMAGING

Radiation exposure during suborbital flight will be minimal to the space tourist on current proposed suborbital trajectories, even under worst-case conditions. The low altitudes and magnetospheric protection limit radiation levels, and the minute flight times greatly reduce exposure.

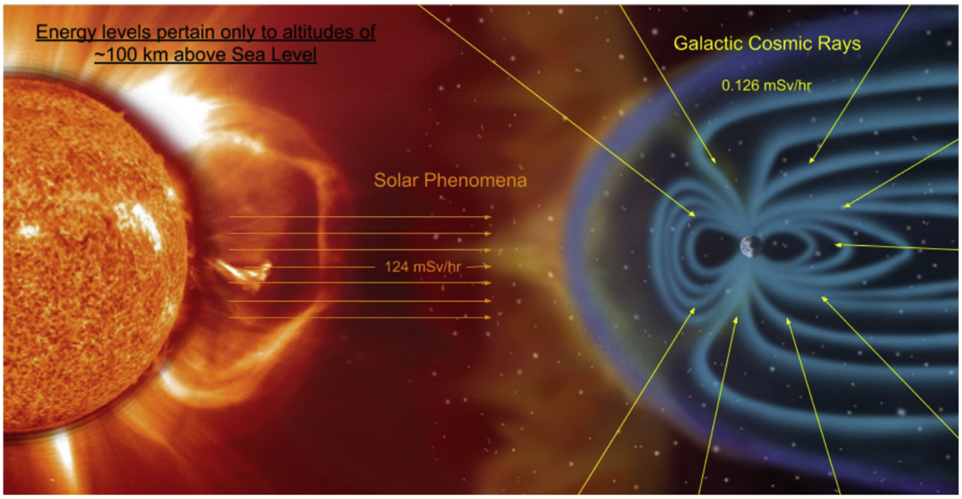

Fig 1. Diagram showing estimated upper limit radiation dose levels from both galactic cosmic rays (GCRs) and acute solar phenomena at 100 km above sea level. GCR data based on data obtained from Federal Aviation Administration's CARI-7 program. Solar phenomena data based on dose estimations during the largest solar phenomena recorded by modern-day equipment, August 1972. Adapted from National Aeronautics and Space Administration.

Table 1. Relative effective dose including planned Mars mission

Exposure	Effective Dose (mSv)
Most likely suborbital flight	~0.005
70 bananas	~0.007
2- to 3-h airplane flight	~0.007
PA and lateral chest radiograph	0.1
Average annual radon worldwide	1.15
Average annual natural background	3
ERCP	4
Worst-case suborbital flight	11.39
Triple-phase liver CT	15
Mars mission	1,000

ERCP = endoscopic retrograde cholangiopancreatography; PA = posteroanterior.

The deterministic doses of radiation needed to affect the human body are well documented in radiology literature (ie, cataractogenesis starting at around 0.5-2 Sv for an acute deterministic dose or 5 Sv protracted exposure; acute radiation sickness traditionally starting at 2 Sv). Realistically, exposure for currently planned suborbital space tourist flights will rarely exceed a few microsieverts. Even in the overestimated worst-case scenario of approximately 11.39 mSv maximum exposure (which includes launching at the magnetic poles and maintaining peak altitudes for the entirety of flight), radiation dose relative risk is still quite small.

Although it is not optimal to compare voluntary radiation exposures to medically necessary exposures, we consider some here. The most likely effective dose received from the proposed flight plans, a few microsieverts, is orders of magnitude less than a posteroanterior and lateral chest radiograph. These average 0.1 mSv [15], or approximately the same effective dose received from an average 2- to 3-hour airline flight [16]. Alternatively, one could use a unit commonly employed, comparison to effective doses from bananas, to convey information to the public: 70 banana equivalent dose [16]. Even assuming one would be caught in one of the worst solar events of the last 50 years, the approximated effective dose would be less than an average triple-phase liver CT of about 15 mSv, or similar to the exposure from normal background radiation on Earth for 4 years (3 mSv annually [15]). As we travel longer and venture further out into space, it is important to note that these numbers will become more of a problem. For example, the vastly higher potential predicted exposures for a multiyear Mars mission is approximately 1 Sv [17] (Table 1, Fig. 2).

Although space radiation is theorized to have a larger impact on health outcomes compared with terrestrial radiation, expected doses for suborbital tourist flight are still

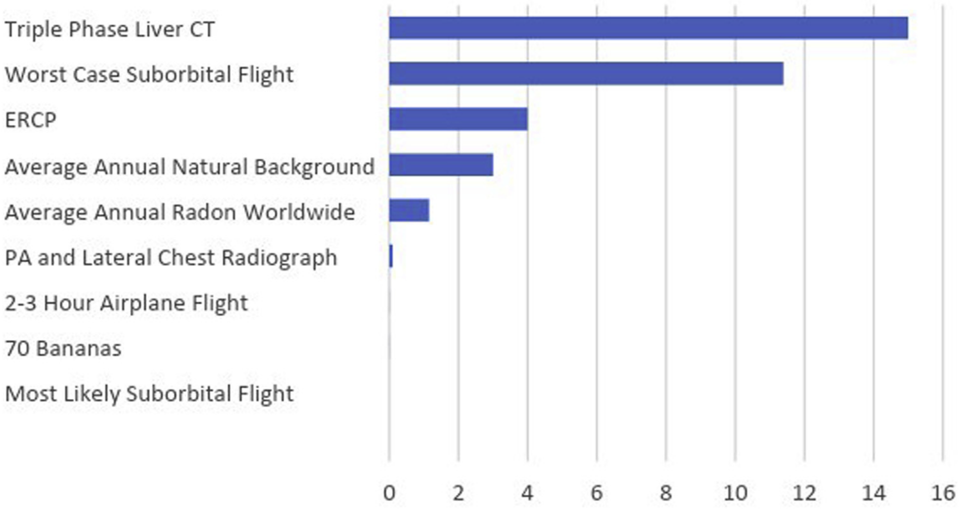

Fig 2. Relative effective doses in millisieverts. ERCP = endoscopic retrograde cholangiopancreatography; PA = posteroanterior.

exceedingly below acceptable dose levels for common medical imaging examinations. Assuming the linear nonthreshold model, any exposure technically increases the risk of developing solid and blood-based cancers. However, the cumulative exposure from a tourist-based suborbital flight, even in the worst conditions in a 50-year history, would be less than or equivalent to commonly performed radiologic studies.

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