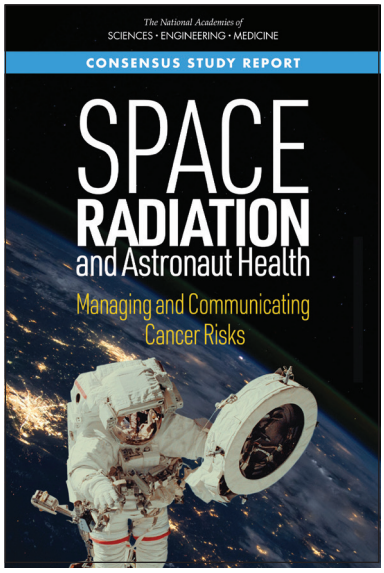
Consensus Study Report
HIGHLIGHTS
JUNE 2021

Space Radiation and Astronaut Health: Managing and Communicating Cancer Risks



Astronauts face unique health-related risks during crewed space missions, and longer-duration missions that extend to greater distances in our solar system (including to the Moon and Mars) will likely increase those risks. Cancer risks due to ionizing radiation (referred to as *radiation* hereafter) exposure are one of these health-related risks. Assessing, managing, and communicating radiation-induced cancer risks associated with space exploration are challenging because of incomplete knowledge of the radiation environment in space, limited data on radiation-induced cellular damage mechanisms, lack of direct observations from epidemiological studies, and the complexities of understanding radiation risk. At the request of the National Aeronautics and Space Administration (NASA), an ad hoc committee of the National Academies of Sciences, Engineering, and Medicine convened to provide advice on NASA's proposed updates to the space radiation health standard that sets the allowable limit from radiation exposure received by an astronaut throughout their career. The committee was not asked to develop a new space radiation standard nor to perform a detailed evaluation of NASA's cancer risk model that is used to derive the standard.

NASA'S CURRENT SPACE RADIATION HEALTH STANDARD

NASA's current space radiation health standard is a quantifiable limit of exposure to a component of the environment during spaceflight over the course of an astronaut's career. The standard is derived by the probability of death from cancer associated with the radiation exposure and informs crew mission assignments, crew health care, space vehicle design, and operational profiles for human spaceflight missions.

The current standard sets career exposure to radiation to not exceed 3 percent risk of exposure-induced death (REID) for cancer mortality at a 95 percent confidence level to limit the cumulative effective dose received throughout an astronaut's career. This means that a male astronaut's career radiation exposure limit would be reached with a 211-day mission to the International Space Station (ISS), whereas a female astronaut's exposure limit would limit her to a 43-day mission to the ISS. The current standard is for low Earth orbit missions

exclusively, so an updated standard was needed for longer-duration missions that extend to greater distances in our solar system.

PROPOSED UPDATED SPACE RADIATION HEALTH STANDARD

NASA is proposing to move from a standard conveyed as a risk limit to a standard still based on risk but conveyed as a dose-based limit for radiation exposure during spaceflight over the course of an astronaut's career. The proposed limit of approximately 600 millisieverts (mSv) was determined by NASA by applying NASA's cancer risk model to the most susceptible individual (i.e., a 35-year-old female) to calculate the mean REID, which was then converted to an effective-dose value. NASA proposed that this limit be applied universally for all ages and sexes. While the 3 percent REID underlying NASA's approach has been used since 1989, the occupation hazards at the time that informed acceptable risks have changed and are constantly evolving. The committee concludes an important, near-term opportunity exists for NASA to conduct an independent analysis of the validity of 3 percent REID.

ETHICAL AND POLICY CONSIDERATIONS

The committee's analysis includes scientific and ethical considerations related to the components that make up the proposed revised standard, as well as the implications of their relationship and combination as part of a new health standard. The three components of NASA's proposed revised radiation standard are summarized below.

Commitment to a single standard for male and female astronauts: A single radiation standard that applies to all astronauts regardless of sex and age would provide equality of opportunity. The current standard limits female astronauts to shorter spaceflight careers, based on data indicating that females have a reported increase of some specific cancers from exposure to ionizing radiation compared to males. Applying a single dose-based limit to male and female astronauts also aligns NASA with the majority of its international space agency partners.

Selection of the age and sex category on which to base the standard: NASA's proposal that the universal standard be based on the mean REID using a 35-year-old female as the reference is the most protective approach because this age group is at the highest risk. This approach sets a single dose limit for all astronauts, but it also could result in a more restrictive limit for some male astronauts than a more individualized approach would allow.

Choices made in setting a dose limit: NASA proposes using the mean (50 percent confidence level) value for REID and resulting exposure limit, a change from its current standard, which is based on the 95 percent confidence level. Using the mean REID results in a higher dose limit than the one extrapolated currently, which conflicts with an ethics commitment to protection from harm, minimization of risk, and NASA's principal of keeping exposures as low as reasonably achievable. Revised calculations for dose threshold within the limits imposed by 3 percent REID may be acceptable with appropriate justification. Using the mean will warrant focused attention on communicating with astronauts about the uncertainties around the exposure limit.

IMPLICATIONS OF THE PROPOSED RADIATION HEALTH STANDARD

Compared with the current standard, the proposed standard will increase the allowable radiation exposure for a 35-year-old female by a factor of ~3 and for a 55-year-old male by a factor of ~1.5. Future revisions to this standard could be warranted if, for example, improved models suggest that 3 percent REID is associated with a different dose, or if NASA determines that a different REID cutoff is justified as more appropriate. Overall, NASA's proposed standard creates equality of opportunity for spaceflight with the trade-offs of higher allowable radiation exposure for a subset of astronauts (primarily female) and limiting exposures below otherwise acceptable doses for others (primarily older male astronauts). It will be important for NASA to offer explicit ethics justifications for the approach adopted and the resulting standard, to be shared with astronauts and their families as well as the public.

COMMUNICATING RADIATION-INDUCED CANCER RISKS

A key component of risk management is evidence-based, thorough, and effective communication of the risks. In the context of NASA's space radiation standard, risk management requires an understanding of the risks and the standard itself, as well as an understanding of how astronauts understand and interpret the risks, related standards, and both formal and informal communications about them. Visual aids can improve risk understanding and

health-relevant decision making. Graphical presentations such as gradient bands, probability density functions, or cumulative distributions can help illustrate the central tendency and associated uncertainty in estimated risk. NASA proposes conveying the standard in a traffic light color-coded risk matrix with each of the three bands (green, yellow, red) representing increased risk. Each risk band contains numerical and evaluative information about the risk, as well as information about the impact on crew assignment. For example, radiation exposures in the red band exceed the dose-based limit and would require a waiver for the mission or individual astronaut to continue with spaceflight. The committee notes that the categorization of risk consequences in the traffic light matrix is subjective, as it reflects a specific risk attitude, so transparency from NASA about how risk categorization decisions are made is important.

CONCLUSIONS AND RECOMMENDATIONS

The committee recommended that NASA proceed with the proposed approaches to revising the space radiation health standard, including applying a single, dose-based standard to all astronauts, set to utilize the most protective approach. The committee also recommended that when setting the standard, NASA should utilize the mean value of the risk distribution based on a 3 percent REID, though it noted that NASA should re-examine whether this is the best metric to use moving forward.

The committee also provided recommendations regarding NASA's radiation risk communication strategies. First, the committee recommended that NASA provide all astronauts with an individual risk assessment when communicating about the radiation health standard. The committee also recommended that NASA communicate a comprehensive picture of an individual astronaut's cancer risks, to place the radiation exposure–induced risk in context. Without empirical evidence, the committee could not determine whether NASA's proposed communication strategies are effective. Therefore, the committee recommended that NASA develop a radiation risk communication research agenda and provided suggestions for revising NASA's proposed radiation risk communication tool.

Finally, the committee concluded that astronauts who travel on long-duration spaceflight missions are likely to be exposed to radiation levels that exceed the proposed standard and recommended that NASA develop a protocol for waiver of the proposed space radiation standard that is judicious, transparent, and informed by ethics. For further details about the conclusions and recommendations, view the Recommendations and Conclusions insert.

Committee on Assessment of Strategies for Managing Cancer Risks Associated with Radiation Exposure During Crewed Space Missions

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