MIND THE GAP: EXPLORING THE UNDERGROUND OF THE NASA SPACE CANCER RISK MODEL

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Radiation exposure is one of many risks inherent to space travel. Radiation exposure over an astronaut's career is limited, as defined in the NASA Standard 3001 [1], by the space permissible exposure limit (SPEL) that states:

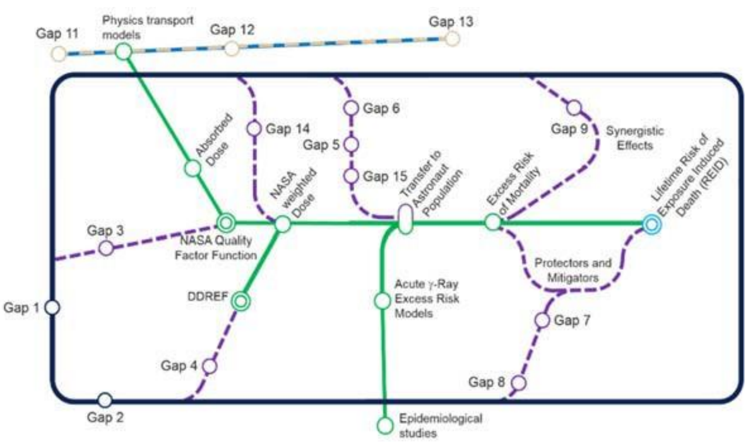
Planned career exposure to ionizing radiation shall not exceed 3 percent Risk of Exposure-Induced Death (REID) for cancer mortality at a 95 percent confidence level.

The REID quantifies the lifetime risk of death from radiation-induced cancer in an exposed astronaut. The NASA Space Cancer Risk (NSCR) 2012 model [2] incorporates elements from physics, biology, epidemiology, and statistics to generate the REID distribution. The current model quantifies the space radiation environment, radiation quality, and dose-rate effects to estimate a NASA-weighted dose. This weighted dose is mapped to the excess risk of radiation-induced cancer mortality from acute exposures to gamma rays and then transferred to an astronaut population. Finally, the REID is determined by integrating this risk over the individual's lifetime. The calculated upper 95% confidence limit of the REID is used to restrict an astronaut's permissible mission duration (PMD) for a proposed mission. As a statistical quantity characterized by broad, subjective uncertainties, REID estimates for space missions result in wide distributions. Currently, the upper 95% confidence level is over 350% larger than the mean REID value, which can severely limit an astronaut's PMD.

The model incorporates inputs from multiple scientific disciplines in the risk estimation process. Physics and particle transport models calculate how radiation moves through space, penetrates spacecraft, and makes its way to the human beings onboard. Epidemiological studies of exposures from atomic bombings, medical treatments, and power plants are used to quantify health risks from acute and chronic low linear energy transfer (LET) ionizing radiation. Biological studies in cellular and animal models using radiation at various LETs and energies inform quality metrics for ions present in space radiation. Statistical methodologies unite these elements, controlling for mathematical and scientific uncertainty and variability. Despite current progress, these research platforms contain knowledge gaps contributing to the large uncertainties still present in the model. The NASA Space Radiation Program Element (SRPE) defines the *knowledge gaps* that impact our understanding of the cancer risks. These gaps are outlined in NASA's Human Research Roadmap [4], which identifies the research questions and actions recommended for reducing the uncertainty in the current NSCR model and for formulation of future models.

The greatest contributors to uncertainty in the current model include radiation quality, dose rate effects, and the transfer of exposure-based risk from other populations to an astronaut population. Future formulations of the risk model may benefit from including other potential sources of uncertainty such as space dosimetry, errors in human epidemiology data, and the impact of microgravity and other spaceflight stressors [3]. Here, we discuss the current capabilities of the NSCR-2012 model and several immediate research needs, highlighting areas expected to have an operational impact on the current model schema.

The following subway-style route map outlines the NSCR-2012 model (Green Line), emphasizing the research gaps in the Human Research Roadmap for risk of radiation-induced carcinogenesis (Stops on Dashed Lines). The map diagrams how these research gaps feed specific portions of the model.



Subway-style notional map featuring the NSCR-2012 model and associated uncertainties. Diagram may change to accommodate future input
DDREF: Dose and Dose Rate Effectiveness Factor

REFERENCES

[1] *NASA Technical Standard, NASA-STD-3001, Vol. 1, Revision A*. [2] Cucinotta F.A., Kim M.Y., and Chappell L.J. (2013) *NASA JSC TP 2013-217375*. [3] Cucinotta and Durante. (2008) Nat Rev Cancer 8:465-471. [4] NASA HRP (2016) *https://humanresearchroadmap.nasa.gov/Risks/risk.aspx?i=96*. Accessed Oct 26 2016.